Sustainable Electric Arc Furnace Steel Production: GreenEAF

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Sustainable Electric Arc Furnace Steel Production: GreenEAF
Nachhaltige Stahlproduktion im Elektrolichtbogenofen: GreenEAF

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Abstract

In the modern electric arc furnace (EAF) more than 40% of energy comes from chemical sources by fossil fuels: natural gas is used in dedicated burner during the melting of the scrap while coal (mainly anthracite), lump in the basket and pulverized by wall injector, is used as foaming agent.

In the frame of the European Research Fund for Coal and Steel (RFCS), the ongoing project GREENEAF (RFSR-CT-2009-004), is studying the possibility to replace coal and natural gas in EAF with char and syngas produced by biomass pyrolysis.

The best pyrolysis conditions to obtain the proper syngas and char quality has been defined by laboratory tests using biomass available in the surrounding of the partners steel shops. Industrial trials have been performed in three different EAF plants. The results demonstrated the technical feasibility of the approaches while the economical evaluation has showed the sustainability of replacing the coal with char from biomass, in addition to environmental benefits due to CO_2 reduction.

Keywords

Biomass, CO_2, greenhouse gas, EAF, steelmaking, pyrolysis, char

Zusammenfassung

Im modernen Elektrolichtbogenofen (EAF) werden mehr als 40% der Energie in Form chemischer Energie durch fossile Brennstoffe eingebracht: Erdgas wird in Brennern während des Einschmelzens des Schrott verwendet, während Kohle (hauptsächlich Anthrazit) stückig im Schrottkorb und in Form von Pulver über Wandinjektoren als Schäummittel eingesetzt wird.

Im Rahmen des Europäischen Forschungsfonds für Kohle und Stahl (RFCS) untersucht das laufende Projekt GREENEAF (RFSR-CT-2009-004) die Möglichkeit, Kohle und Erdgas im EAF durch Holzkohle und Synthesegas aus der Biomassepyrolyse zu ersetzen.

In Laboruntersuchungen wurde unter Verwendung von Biomasse, die in der Umgebung der beteiligten Stahlwerke zur Verfügung steht, die besten Pyrolysebedingungen bestimmt, um Synthesegas und Holzkohle in geeigneter Qualität herzustellen. Versuche im industriellen Maßstab wurden in drei unterschiedlichen Elektrostahlwerken durchgeführt. Die Ergebnisse konnten die technische Umsetzbarkeit des Ansatzes aufzeigen, während die ökonomische Evaluation die Nachhaltigkeit einer Substitution von fossiler Kohle mit Holzkohle aus Biomasse zusätzlich zum ökologischen Nutzen aufgrund der Reduktion der CO_2-Emissionen zeigen konnte.

1. Introduction

In the modern electric arc furnace (EAF) more than 40% of energy comes from chemical sources by fossil fuels: natural gas is used in dedicated burner during the melting of the scrap while coal (mainly anthracite), lump in the basket and pulverized by wall injector, is used as foaming agent[1].

The partial introduction of biomass in steel production is considered a good option to reduce the environmental impact and greenhouse gas emission [2,3]. Moreover it can be considered an economical option in relation with increasing prices of oil, coal and market of CO_2 quotes.

The ECSC project “Sustainable EAF Steel Production – GREENEAF” started in the year 2009 to study the EAF cycle in order to investigate the partial or total substitution of coal and natural gas with charcoal and syngas produced from pyrolysis of biomass.

Generally speaking, in the electric furnace coal (and consequently char) can be used as injected powder or charged into the basket. The syngas can be used for EAF burners.

The characteristics of char and syngas, and the related pyrolysis process, must be tailored in order to match the requirements for their utilization in EAF.

Biomass selection and classification respect their origin and characterization have been done and laboratory tests to define the pyrolysis kinetics of the selected biomass, and on the basis of these results design of industrial pyrolysis; then chemical and physical characterizations of char produced by biomass pyrolysis have been carried out to define pyrolysis plant process parameters. About fifteen tons of char have been produced for pilot and industrial trials. Due to the difficulties to have syngas available close to the steel plant, the use in EAF burners has been simulated by CFD calculation. The results of CFD simulation are not presented in this paper.

2. Biomass selection for EAF char production

The first activity was aimed to analyse the availability and the quality of biomass in the area around the steel plants participating to the project: Ferriere Nord (Italy), DEW (Germany) and MH (Austria). The following biomass species have been selected:

- Ligneous biomass and forest residues (including ligneous species as saw dust for pellets or pulp)

- grapewine and corn stalk as agricultural residues

- mischantus and sorghum as biomass from cultivations

Samples of the biomass of types described have been collected and characterized in terms of: physico-chemical characterization (Table 1) and pyrolysis behavior.

TABLE 1 - Characterization activities performed on selected biomass

	Ligneous biomass	**Corn straw**	**Grapewine**	**Mischanthus**
LHV* [kJ/kg]	20000	18000	18900	19100
Volatiles (%)	80	76-81	78	78
Ash (%)	1.1	5.5	3.9	3.5
C (%)	51.5	47.3	46.2	48.2
H (%)	6.7	5.4	5.5	5.4
N (%)	0.3	0.8	1.3	0.6
O (%)	39.7	43.2	37.7	42.1
S (%)	0.04	0.05	0.03	0.06
Cl (%)	0.05	0.2	0.05	0.2

** Lower Heating Value*

The performed analysis showed that the selected biomasses have very similar elemental analysis in terms of C/H/O and similar volatile matter content. Biomasses heating value is also very similar. Main differences can be found in minor elements (as N, S and Cl) and ash amount.

Pyrolysis products from biomass are charcoal, condensable vapors and syngas. The percentages and characteristics of formed products depend on pyrolysis heating rate, residence time and reaction temperature. For this reason, a laboratory activity has been carried out to study thermal behavior of selected biomass with the purpose to define the best conditions for the pyrolysis in order to obtain a char suitable as charge material in the basket of injected to promote slag foaming.

3. Definition of the pyrolysis conditions

Laboratory tests have been purposely carried out to define the pyrolysis conditions. Tests are carried out with thermobalance (TGA tests) to follow the weight variations of the material as a function of temperature, under controlled atmosphere. TGA tests have been carried out on biomass, to obtain information about pyrolysis kinetic and on char, to compare the reactivity of char with reactivity of standard used coals.

3.1 Characteristics pyrolysis temperatures

Three biomass samples were used: agricultural residues, biomass from cultivations and wood biomass. Figure 1 reports an example of TGA curve (expressed as derivative of weight loss with temperature) obtained with agricultural residues.

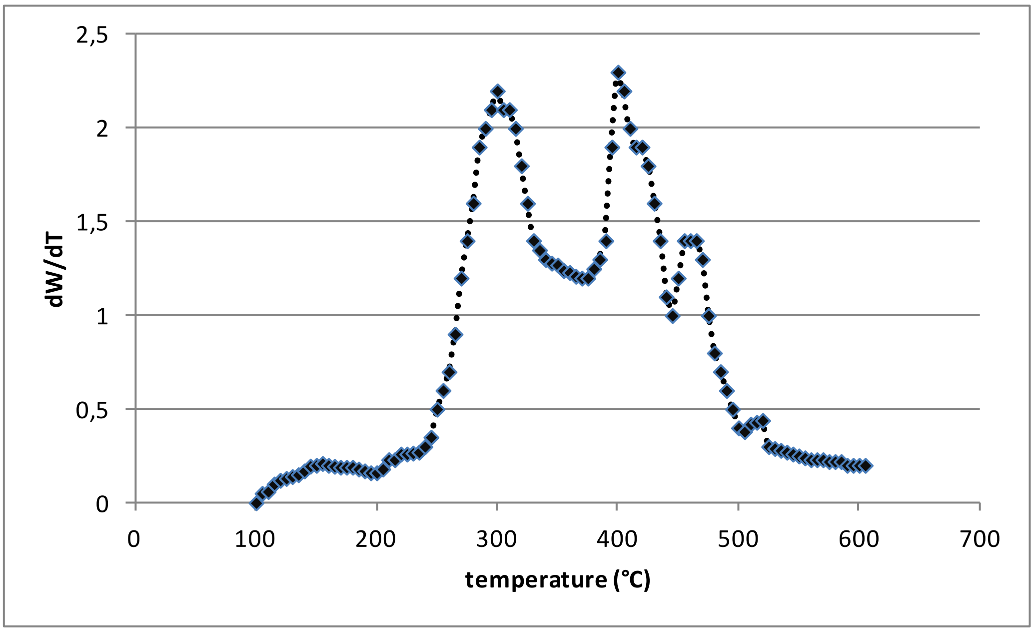


Fig. 1: TGA test of biomass (agricultural residue) expressed as derivative of weight loss with temperature

TG tests showed that pyrolysis process starts at about 200°C for all the biomass samples, with two peaks centered at about 300°C and 400°C; the temperature of 400°C can be considered the minimum temperature for the biomass pyrolysis process.

3.2 Char yeld

An important result is that, after 500°C, the char yield is almost stable, and this result does not depend on the biomass type. Figure 2 reports Char yield as a percentage of the original biomass (dry basis) as a function of temperature (°C) in experiments conducted in laboratory pyrolysis furnace.

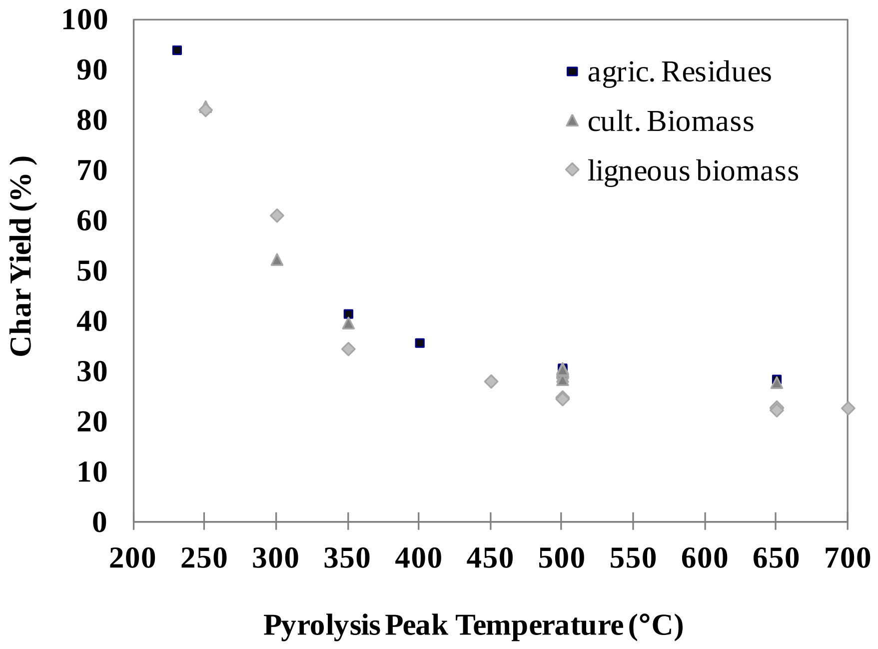


Fig. 2: Char yield for three different biomasses

3.3 Char and syngas heting value

Char composition depends very slightly from starting biomass type, but char heating value depend mainly on pyrolysis condition.

Syngas composition has been determined connecting a mass spectrometer to the TGA apparatus. As an example, Figure 3 compares char and syngas heating value as a function of pyrolysis temperature. Char heating value is measured, while syngas heating value is calculated from syngas composition measured with mass spectrometer during TG test (Figure 3).

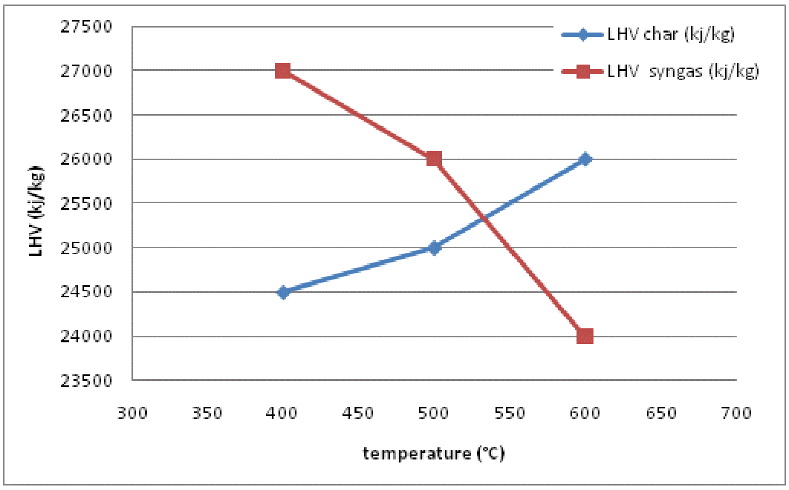


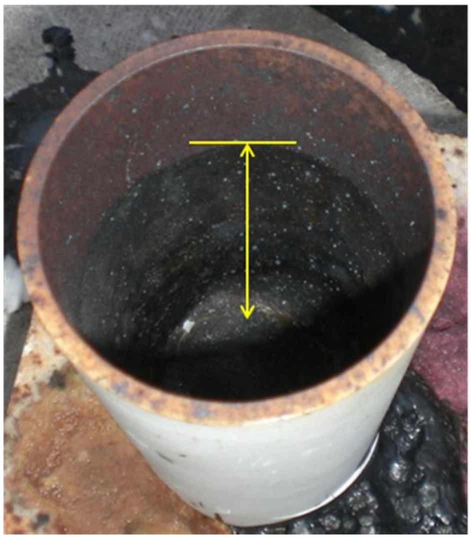
Fig. 3: Heating value of syngas and char as a function of pyrolysis temperature

3.4 Foaming behavior

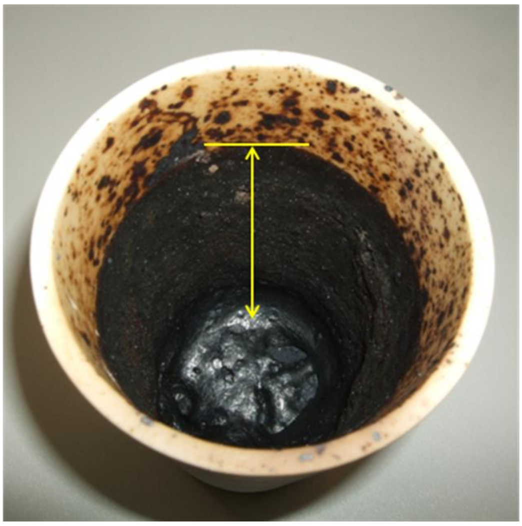
Preliminary laboratory tests were carried out to have a first evaluation of char vs coal foaming behaviour. The trials have been conducted using slag sampled from the DEW EAF right before slag foaming. Foaming slag is carried out into alumina crucible, filled with a mixture of pulverized char or coal and put into a furnace at 1600°C. Char produced in laboratory furnace at different temperatures (400°C, 500°C and 600°C) were used for foaming laboratory trials.

The foaming tendency of coal and char is estimated from the measurement of the height of the foam produced into the crucible. Figure 5 shows pictures of the crucibles after the slag foaming trials. Within these pictures the foamy slag height reached during the trial is marked. The foaming behaviour of the different chars has been compared with foaming behaviour of standard coals.

The achieved volume increases clearly show the general suitability of the char for slag foaming. The chars showing foaming capability comparable with coals were the one produced at 400-500°C.



Foaming test with coal



Foaming test with char

Fig. 4: Crucible after laboratory foaming tests

3.5 Char reactivity

The reactivity of the chars produced in laboratory furnace at different temperatures, was assessed in a TGA by both isothermal and non-isothermal methods. The results from the non-isothermal determination are shown in Figure 5 along with the temperature programme applied. An initial step is carried out in an inert atmosphere up to 400°C. The gas is switched to air at 400°C. The chars that have been exposed to higher temperatures present lower reactivities. There are marked differences between the behaviour of the 300ºC char, which shows a high volatile content, and that of the chars produced between 325-450ºC. There are as well significant differences between the latter and those chars generated at 500-600 ºC, which present the same reactivity among themselves, while the 900ºC char is clearly less reactive.

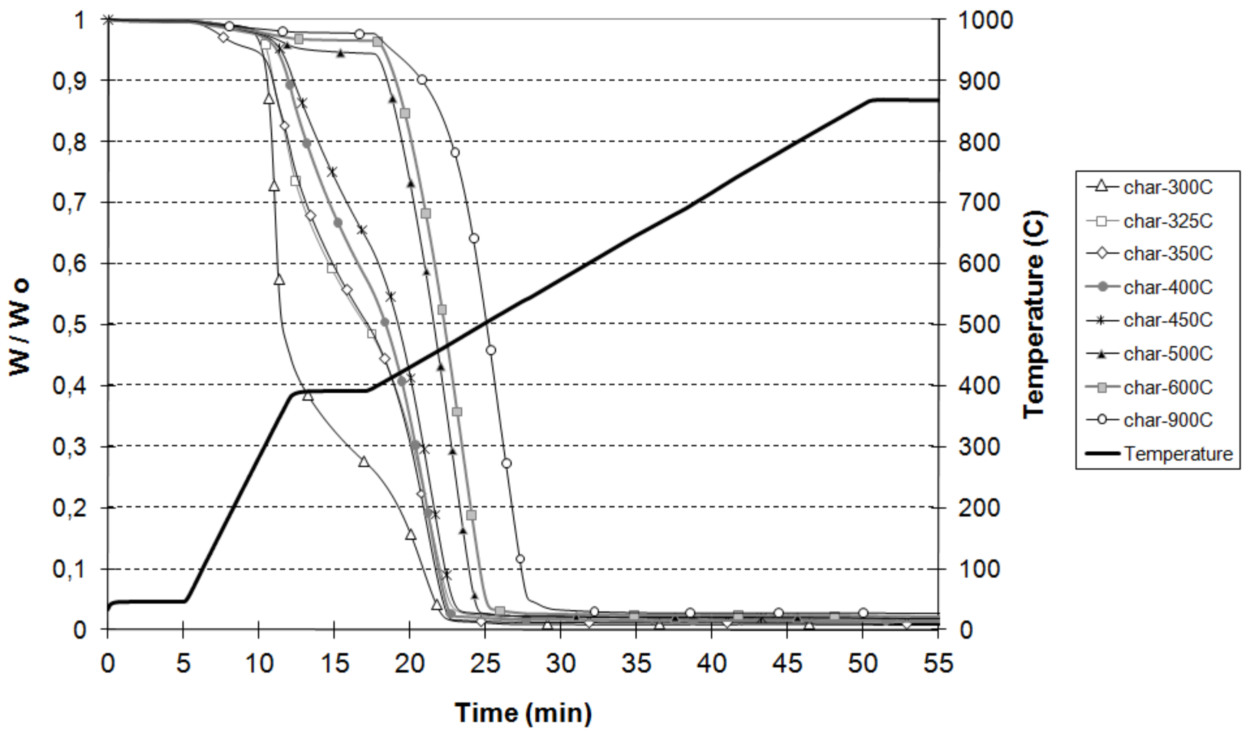


Fig. 5: TGA non-isothermal char reactivity tests of char produced in laboratory furnace.

Chars produced at 500 and 600°C have a reactivity comparable with standard charge coal. A good compromise for pyrolysis temperature can be considered the value of 500°C. In fact this value is the best compromise also for optimization of char and syngas heating value.

The indication given by laboratory tests is that for charge material optimal pyrolysis temperature is in the range 500-600°C, while for foaming purposes the optimal pyrolysis conditions are in the range 400-500°C.

4. Char production

After laboratory pyrolysis test on different kind of biomass, pyrolysis campaigns were carried out on demonstrative plant in order to confirm the laboratory results and to produce material for industrial trials of char charge and injection. The effect of the main process parameters, such as different combination of rate of heating, time of treatment and the rotation speed of pyrolysis reactor have been considerate.

The demonstrative pyrolysis plant can be fed with about 200 kg/h of fuel and the necessary heat energy for pyrolysis reactions is supplied by a gas burner of the maximum power of 500 kW. Is it possible to vary the pyrolysis temperature (monitored continuously by a pyrometer) by means of burner thermal power. Figure 6 shows a photo of the pilot plant.

Fig. 6: Enerpol pyrolysis plant (Tecnocentro)

During the tests, syngas has been burnt in the torch and sampled; tar has been eliminated from the gas in the treatment section and collected in the tank with cooling and washing water. The char, conveyed by a screw, is usually discharged from the and cooled rapidly

The main values of pyrolysis parameters during the tests have been:

- ✓ Biomass feeding to the reactor: 100 kg/h;
- ✓ Pyrolysis temperatures for the tests: 450°C, 550°C, 650°C;
- ✓ Residence time for different tests: 30, 40, 50 min

Table 2 shows the percentages of products (char, syngas, tar) obtained from pyrolysis of different kind of biomasses.

Regarding quality requirements of the carbon source the important factors are the reactivity of the carbon influencing the chemical reactions creating the gas phase. On the other hand the ash content and its composition may influence the EAF slag phase and may change factors like slag viscosity and surface tension.

TABLE 2 - percentages of char, syngas, tar obtained from pyrolysis of different biomasses at 500°C

Biomass type	**Char (%)**	**Syngas (%)**	**Tar (%)**
Ligneous biomass	21	71	8
Agricultural residues	29	49	22
Cultivated biomass	30	60	10

5. Industrial trials

The use of char in EAF has been tested at industrial scale by the three industrial partners participating to the GreenEAF project. The industrial partners involved in this project have different EAF, which differs for size, capacity, and amount of chemical energy. Following Table 3 reports the main EAF characteristics.

Char industrial testing with these three furnaces will exploit a wide range of operational variability. Both char charging and injection have been tested.

FENO uses coal charged and injected for respectively bath carburization and foaming. DEW uses coal mainly for bath carburization: coal is manly charged and injected in a small amount. DEW and MH uses coal for foaming: coal only injected.

TABLE 3 - Main characteristics of the electric furnaces of the industrial partners participating to the project

	Charge weight (TLS)	Num. buckets /heat	Electrical energy input [kWh/TLS]	CH_4 [Nm3/TLS]	O_2 [Nm3/TLS]	Coal lump [kg/TLS]	Injected Coal [kg/TLS]	Power on [min]	Tap to tap [min]
FENO	140	3	341	6	42	4	8	38	45
DEW	130	2	417,2	0	21,8	10.7	1,53	54	69
MH	40	3	375	7	45	0	12	31	45

FENO: Ferriere Nord
DEW: Deutsche Edelstahlwerke GmbH
MH: Marienhütte Ges. m.b.h.

Charged char tests

Substitution of charged coal with char has been tested by Ferriere Nord and DEW, using char produced at 550°C. Charged coal can be needed to reach certain carbon levels in the steel depending on scrap qualities available. It can also be used to substitute electrical energy by chemical energy when oxygen is used to decarburize the melt and the carbon is burned to CO and CO_2 respectively.

Ferriere Nord uses about 1 ton of coal per heat, while DEW about 1.4 tons of coal per heat. The Electric furnace of Ferriere Nord is equipped also with the offgas online monitoring system EFSOP^{TM}.

The average of steel and slag analysis with char charged in 5 heats has been compared with the average of 5 standard heats. Figure 7 reports the comparison of average values of steel and slag analysis measured at DEW in standard and trials heats.

The results from steel and slag analysis show no significant differences.

Off gas analysis system (EFSOP analyzer) in Ferriere Nord has been used during tests. Measured data have been compared with data of the production of $CO/CO_2/H_2$ during standard operations (Table 4).

The main difficulty in char charging is related to high char reactivity. Significant powder dispersion has been noticed during handling and charging operations and intense flame emissions were observed during trials with char.

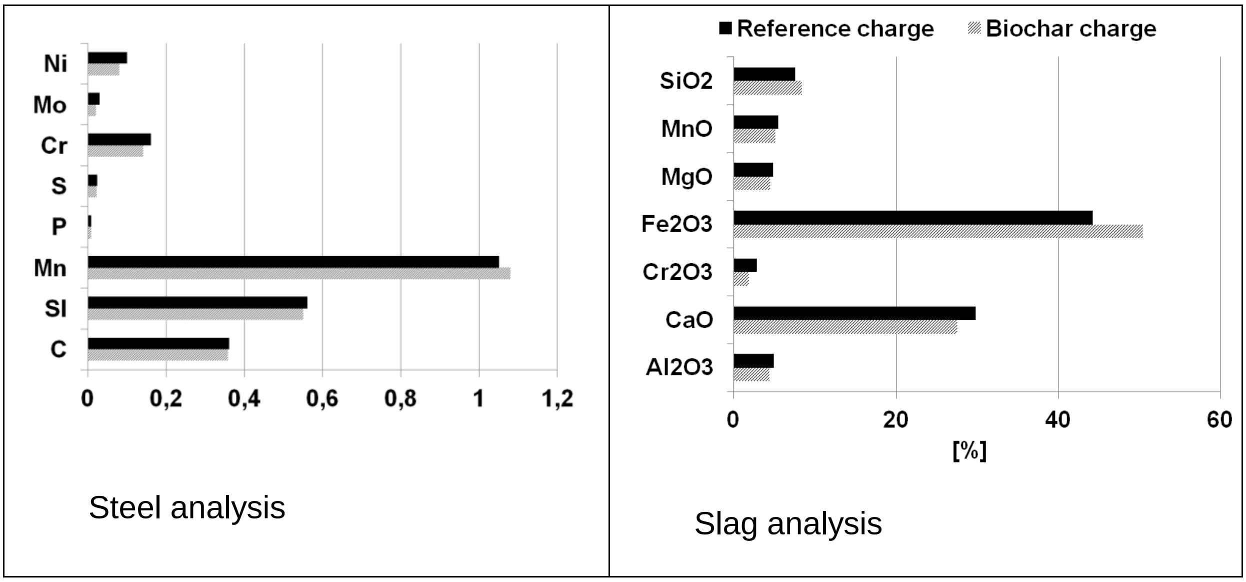


Fig. 7: Comparison of steel and slag analysis of standard and trials heat measured at DEW

TABLE 4 - Average Values of offgas compostion measured during industrial trials at Ferriere Nord

	CO/s*	**CO_2/s***	**H_2/s***	**O_2/s***
Char Trials	16,07	17,34	9,85	0,39
Standard Trials	17,55	16,96	10,19	0,16

<u>Injected char trials</u>

Foaming trials were carried out by the three industrial partners, using char produced at 450°C. Slag foaming is a very complex equilibria depending on slag properties (mainly viscosity and surface tension), amount of injected coal (which affect the amount of gaseous species necessary to promote foaming) and also coal reactivity. So, beside the energetic input, the foaming behavior is an important process aspect which must be taken into account for industrial testing of char.

For a better control of foaming process Marienhütte developed together with VATRON GmbH an Optical Foaming Slag Management System (OFSM). The slag height is detected by a camera continuously. The camera is placed close to the slag door. Special image processing software calculates a slag index to be used for the injection of the carbon amount required. Due to the real-time monitoring of the slag level it is possible to adjust the C-contents by injection of the optimal quantity of carbon. Figure 8 reports the images of three foaming tests with char produced by Tecnocentro.

Injection tests were carried out also by DEW and Ferriere Nord.

Results obtained by the three partners were partially satisfactory, in the sense that in some trials good foaming behavior was observed, while in some poor foaming behavior was observed. These results indicate that injection system must be improved promoting the penetration of char into the slag. On the other hand, it must be taken into account that foaming is a complex equilibrium among different factors and intense industrial testing reproducing the current conditions.

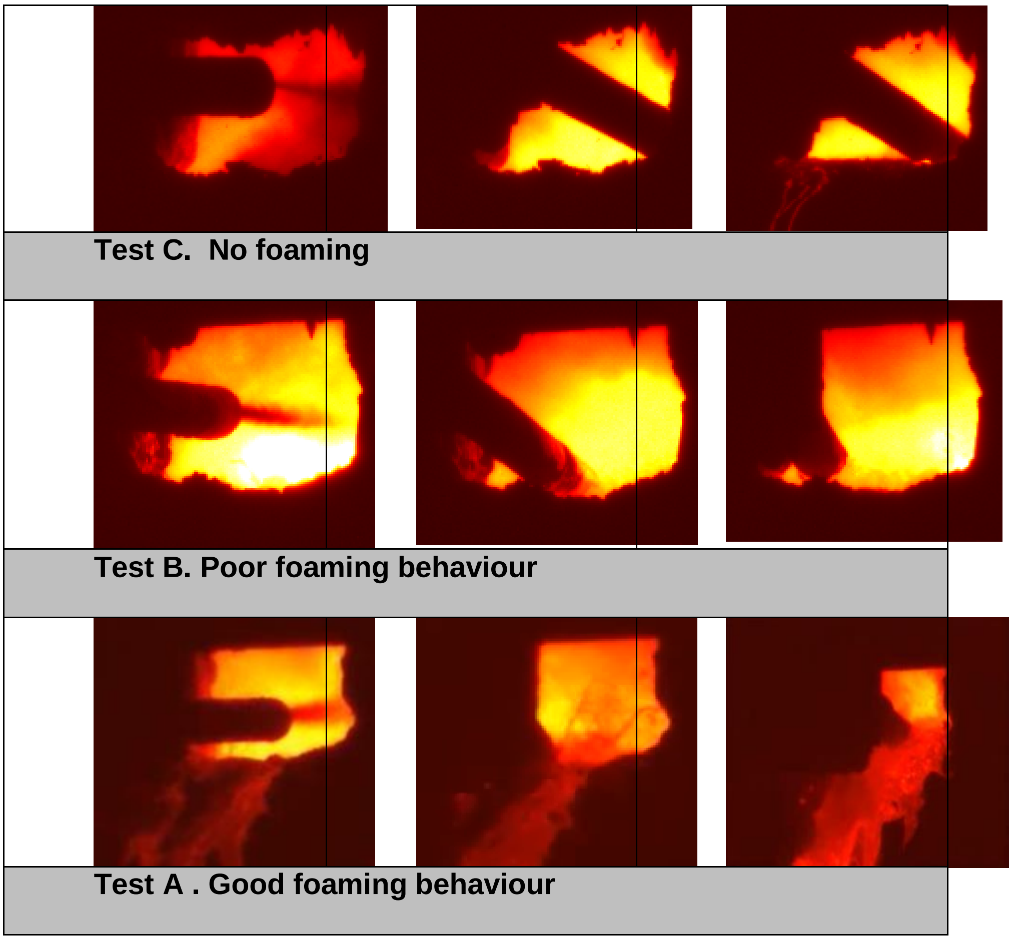


Fig. 8: Foaming tests recorded with Optical Foaming Slag Management System (OFSM installed at Marienhütte

6. Conclusions

The global objective of the project is to investigate the partial or total substitution of coal and natural gas with charcoal and syngas produced from pyrolysis of biomass. The char is used as injectable powder or charged in the basket.

The characteristics of char and syngas, and the related pyrolysis process, are tailored in order to match the requirements for their utilization in EAF.

The tests performed (both pilot and industrial) showed that coal can be replaced by char, both for charging and injection to promote foaming.

In case of charging the following aspects should be deeply investigated:

- char reactivity: char start burning during charging. Char reactivity depends on high surface area, volatile content and powders dispersion during charging. Proposed solution is a char pre-treatment with briquetting stage before charging;

- slag foaming: some trials showed good foaming behaviour, other trials were not satisfactory. Proposed solutions are improvement of injection system and utilization of additives together with char powder to increase char/slag wettability and promote reaction of char with iron oxide. The injection system must ensure char injection below the slag

Moreover syngas utilization in EAF burners instead of natural gas has been investigated in the project GreeEAF. This option, together with the use of char will increase the economical value of biomass use.

Acknowledgments

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