SESSION 1: 10:00–10:20

ESTEP workshop

SecCarb4Steel

Preparation and use of biogenic and non-biogenic secondary carbon carriers (SCC) in processes for iron and steelmaking

Hydrochar as a secondary carbon carrier: A circular approach for low-carbon steel production

Valentina Alemanno[1], Daphne Mirabile[1]

[1] RINA-CSM (Rina Consulting -Centro Sviluppo Materiali SpA)

Introduction

The steel industry is one of the major contributors to global CO_2 emissions, making decarbonization essential for a sustainable future.

The **challenge** lies in **replacing fossil materials** used in steelmaking processes with more sustainable solutions, reducing emissions without compromising process efficiency.

Secondary Carbon Carriers (SCCs) offer an innovative solution to emission reduction and promoting a circular economy approach, by utilizing organic waste and different residues and transformating them in valouable resources.

Secondary Carbon Carrier (SCC)

Secondary Carbon Carriers indicate a set of materials able to act as a carbon source for partial or complete replacement of fossil coal in metallurgical processes.

The utilization of fossil substitute represents a technological option able to mitigate CO_2 emissions without introduction of new technological pathways.

From a first evaluation, SCC can potentially avoid the emission of 300 kg/t of CO_2 in integrated route and 40 kg/t of CO_2 in EAF.

Secondary Carbon Carrier (SCC)

SCCs can be divided into two main groups, according to their origin:

- Biogenic materials (biomass and biochar from biomass)
- Non biogenic materials (polymers, residues from automotive shredder operations, rubber grains from end of life tires..)

SCCs constitute a valid option to avoid fossil utilization in EAF and to increase the circularity of the process, also allowing simultaneaous reutilization of other wastes.

Utilization of SCCs in EAF

Utilization in EAF requires:

- The availability of lumps of proper size, mechanical stability and homogeneous physical-chemical characteristics -> utilization in the basket.
- Controlled grains size distribution, mechanical stability, low fines formation and no tendency to aggregate in the silo -> injection.
- Definition of preliminary pretreatment technology is a fundamental step to ensure an efficient utilization in EAF.

This presentation will be focused on biogenic materials treated with hydrothermal carbonization process and densified into briquettes for utilization in EAF

EAF utilization of SCCs: Briquettes

The densification of material into briquettes is a suitable technological option to re-use materials with different size and shape into EAF.

Briquettes with biochar can be produced to:

- Add carbon to the steel bath
- Provide extra energy input into the EAF
- Allow the reutilization of other waste, such as rolling mill scale, sludges and EAF dusts. In these cases, the reducing capability of hydrochar is also used for material recovery.

RINA-CSM projects

Several projects, based on utilization of SCCs, are currently ongoing.

These projects allowed to optimise the briquettes recipes and to test different materials into EAF, demonstrating the benefit of a circular economy approach of EAF steelmaking

- **BioReSteel** (BIO-based RESidues for iron and STEELmaking): hydrochar utilization
- BioRECAST (BIObased REsidues Conversion to Advanced fuels for sustainable STeel production): conversion from biomass to biochar and bioenergy
- CORALIS (Creation Of new value chain Relations through novel Approaches facilitating Long-term Industrial Symbiosis): developmente and promoting of industrial symbiosis
- ZINCVAL (Valorisation of low zinc-containing residues)

Hydrochar

- **HTC (**Hydrothermal Carbonization**) process**: residual wet biomass, such as fruit peels and vegetable waste, is transformed into hydrochar, using hot water in high pressure conditions. This process is highly efficient and suitable for biomass with high moisture content, making it a key technique in converting agro-food waste into valuable carbon-rich material. It is designed as a sustainable and economically competitive alternative to fossil carbon coke for steelmaking.

- ✓ **Sustainability**: valorization of organic waste, contributing to the reduction of waste sent to landfills and minimization of fossil fuel usage
- ✓ **Economic competitiveness**: Hydrochar production leverages locally available biomass, making it an economically viable solution for reducing the costs associated with traditional fossil coke.
- ✓ **Circular economy:** by utilizing agricultural and food residues, HTC promotes a circular economy approach, converting waste streams into valuable resources for the steel industry

Scopes of the activities

- The activities aim to replacing fossil coal (pet coke and anthracite) used in EAF for bath carburization and slag foaming
- The individuated coal substitute is the hydrobiochar
- This presentation refers to materials characterization and experimental tests at laboratory level
- These are preparatory activities, before industrial trials, to check the suitability of the material for utilization in EAF

Experimental activities

Two different types of **hydrochar samples** have been received by Ingelia.

The materials were characterized (**chemical-physical analysis** and **thermogravimetric analysis** – TGA) before experimental tests.

The different hydrochar samples have been used in **melting tests** (hydrochar in contact with molten iron bath) to check bath carburization capability.

The hydrochar has been also used for **briquettes** production with rolling mill scale. Briquettes have been used in two types of **melting tests**:

- Melting tests of single briquettes, to check the suitability of hydrochar as reducing agent.
- Melting test of briquettes in contact with molten iron bath, to check the occurrence of reduction reaction simulating industrial environment.

Hydrochar – Chemical physical analysis

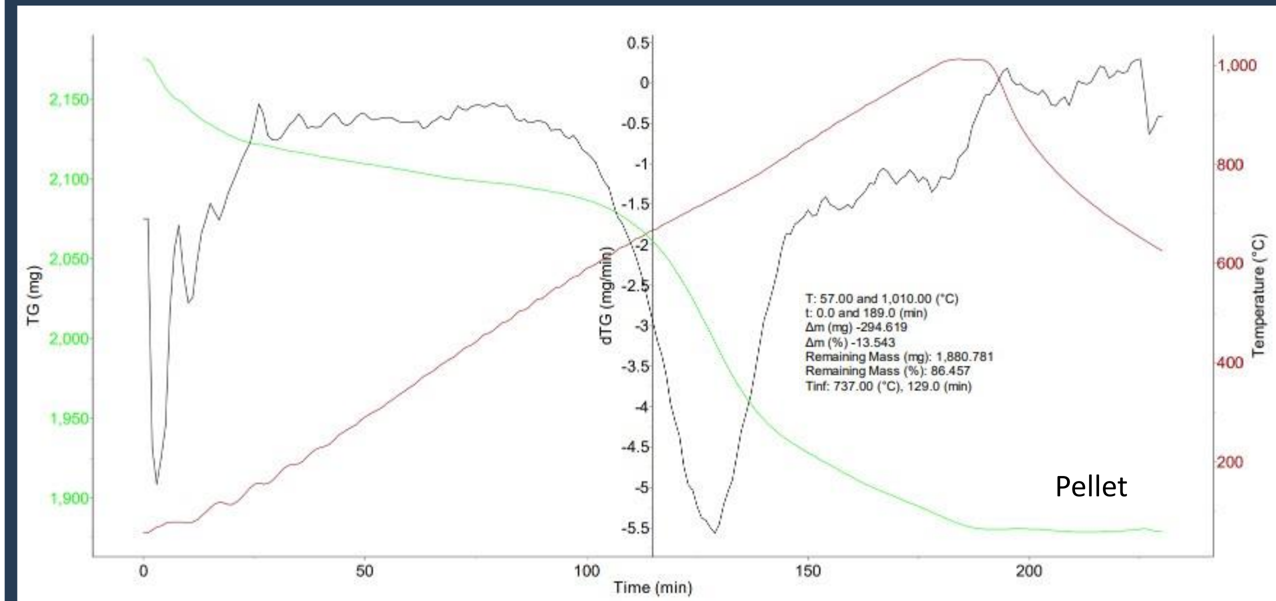
Parameters	Anthracite	Pet coke	Hydrochar powder	Hydrochar pellet
Density (g/cm3)	1,2-1,3	1,2-1,3	0,44	0,79
Humidity (%)			9,62	0,15
Ash (%)	8-14	2,6	**4,62**	**34,38**
Cl (%)			0,025	0,08
S (%)	0,5-1	0,5-1	0,182	0,26
HHV (MJ/kg)	28	28	23,94	19,63
LHV (MJ/kg)	28	26	22,71	19,31
H2 (%)	1-2	<0,1	5,37	1,56
N2 (%)			2,74	0,51
C (%)	85-95	94,5	**58,19**	**42,76**
Volatile matters (%)	2-8	0,7	**89,3**	**58,3**
C fix (%)	80-90	>90	**6,08**	**7,32**
O (%)			21,85	20,47
Pb (mg/kg)			3,2	26
Cd (mg/kg)			<0,06	<0,06
Hg (mg/kg)			<0,10	<0,10

The two different samples of hydrochar, in form of **powder** and in form of **pyrolyzed pellet** (biomass treated with HTC and with further pyrolysis treatment at 500°C), were analyzed and results were compared with reference values of anthracite and pet coke.

Main differences respect reference materials are in ash, C and volatile matter content.

In case of pellets the high ash and volatile matters content could be due from pyrolization process and input material (waste biomass).

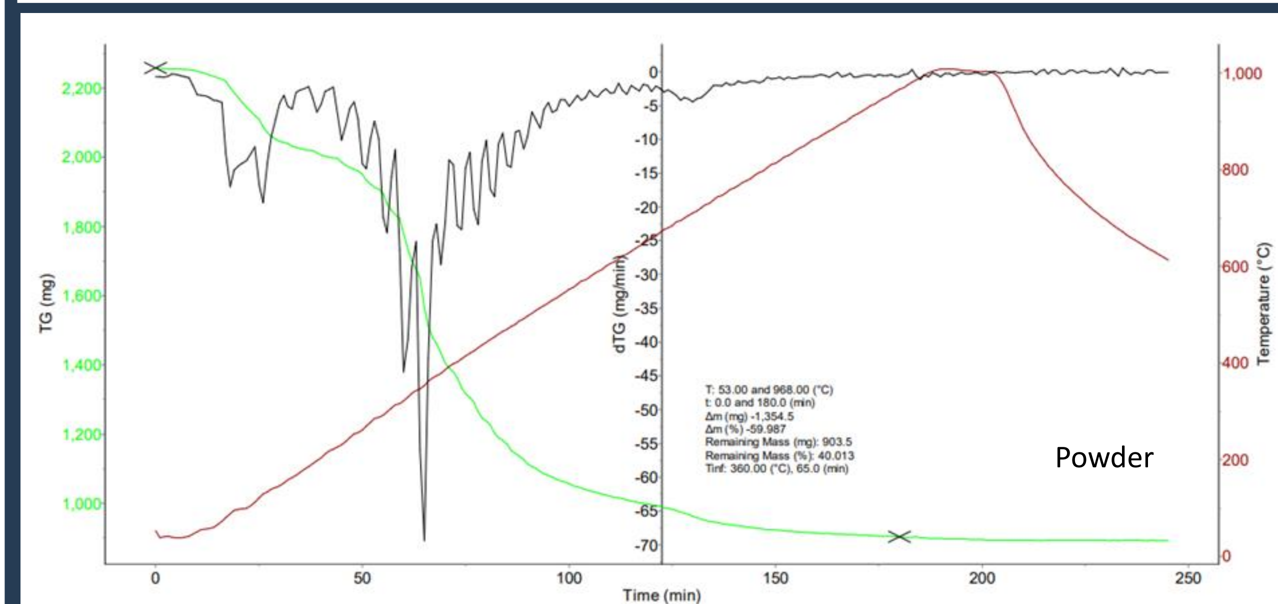
Thermogravimetric analysis (TGA) – N2



Slower and more gradual weight loss. Humidity is almost negligible (0.15%), so the initial weight loss is less pronounced.

The DTG curve is soft, meaning the volatiles are released more slowly than in the powder, likely due to lower specific surface area and higher compactness.

In the end, there is a larger residual mass compared to the powder, due to the higher ash content (34.38%), which provides greater residual stability.



Rapid and significant weight loss at the beginning of the analysis, mainly due to the high humidity (9.62%) and volatile matter (89.3%).

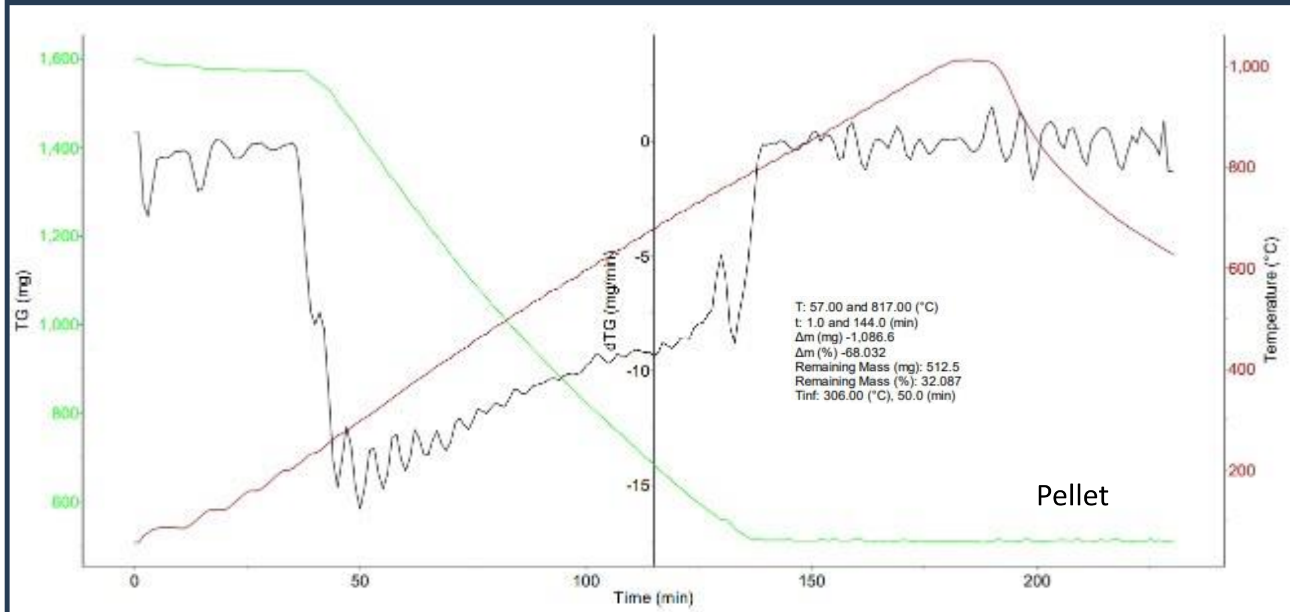
The DTG curve shows more pronounced peaks than the pellet, due to higher volatility and thermal instability.

The overall weight loss is higher compared to the pellet, indicating a more complete decomposition.

ESTEP workshop

SecCarb4Steel

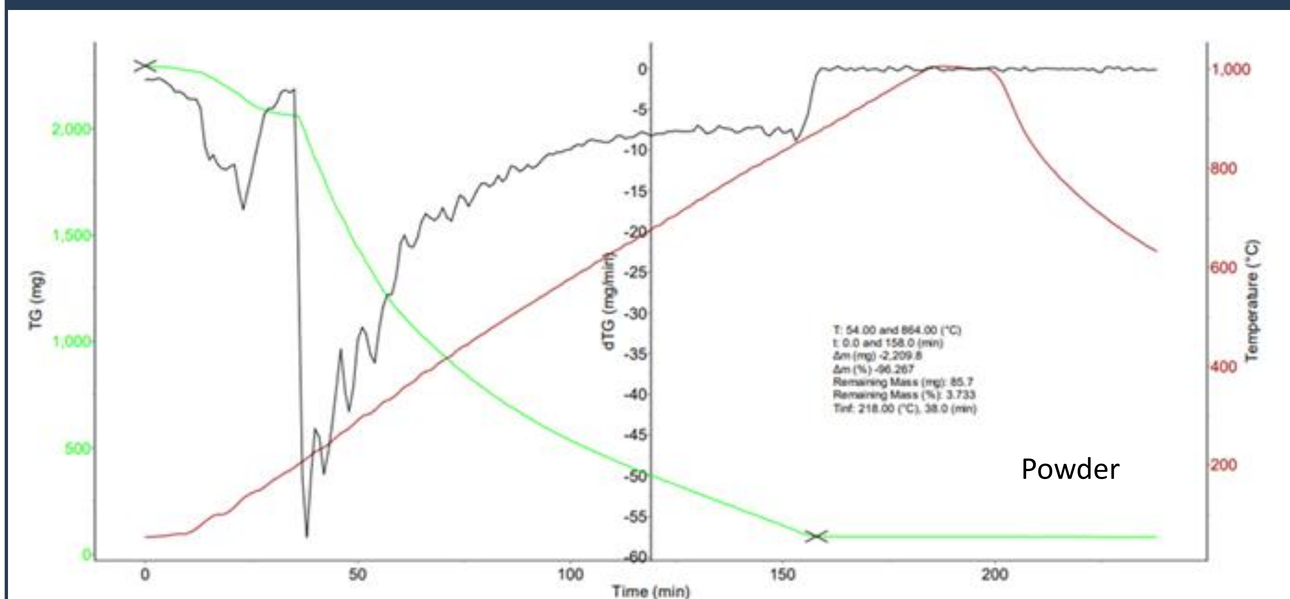
Thermogravimetric analysis (TGA) – air



In air, also the pellet loses weight more gradually, with a less explosive combustion compared to the powder. The pellet burns more slowly.

The presence of ash (34.38%) results in slower combustion and a larger solid residue compared to the powder.

The DTG curve is less pronounced than the powder's, reflecting the more stable and less volatile nature of the pellet.



The weight loss is very rapid at the beginning, similar to inert atmosphere. This is due to the high volatility and the fast combustion of this volatile matters (89.3%).

The DTG curve shows significant peaks, reflecting rapid oxidation and combustion of the material.

Due to its low ash content (4.62%), the powder burns almost completely, leaving very little residue.

Melting tests

Char properties and scope of the tests:

- to what extent could it replace coal in steel production?
- can hydrochar be used as a reducing agent?

Quality of the final product:

- chemical analysis to determine carbon and sulfur, to understand the carburization and the S content

Process optimization:

- different briquette compositions to find the optimal composition for a final product with better chemical-physical properties.

Melting tests were carried out using a BALZERS VSG 10 vacuum induction furnace.

Melting tests

Different types of melting test were conducted:

- Addition of **hydrochar**, in form of powder or pellet, in an iron melted bath
- Briquettes (with hydrochar powder or pellet) made by **RINA-CSM** were melted or added in an iron melted bath
- Briquettes (with hydrochar powder or antracite) made by **ORI Martin** were melted or added in an iron melted bath

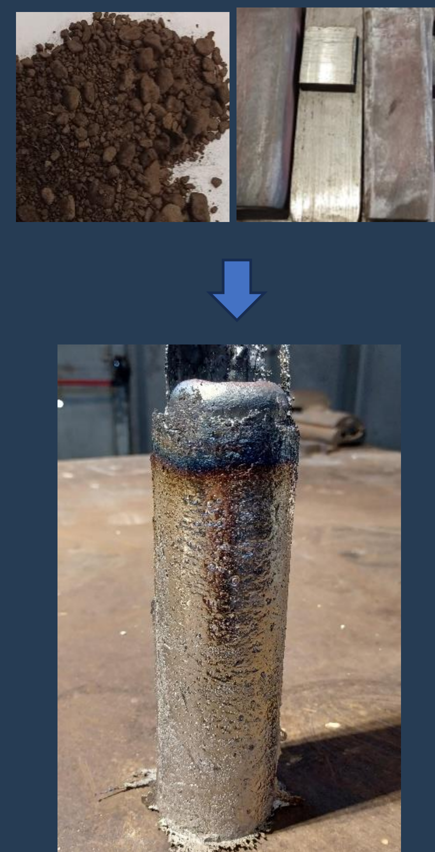
After melting process was complete, an ingot was cast and allowed to cool.

Melting tests – Hydrochar powder and pellet samples

A sample of **hydrochar** (powder or pellet) was added to an iron melted bath.

Ingot percentage of C was:

- 0,15% for powder
- 0,47% for pellet



Hydrochar powder

Hydrochar pellet

Melting tests

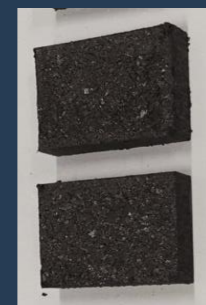
RINA-CSM briquettes with hydrochar powder or pellet


Briquette composition	Iron scale (%)	Hydrochar - Powder (%)	Binder (%)
	65%	21%	15%

Briquette composition	Iron scale (%)	Hydrochar - Pellet (%)	Binder (%)
	65%	21%	15%

Briquettes prepared with a samples of hydrochar in powder or pellet were used for melting tests (melting of the only briquette and addition to a melted iron bath).

In the case of hydrochar powder, neglegible carburisation (<0,01%) has been obtained.
In the case of hydrochar pellet, a more notabile carburisation has been obtained (>0,5%).




Melting tests

ORI Martin briquettes with hydrochar powder or anthracite


Briquette composition (ORI)	Mill scale (%)	Hydrochar (%)	Binder (%)
	77.5%	12.5%	10%

Briquette composition (ORI ref)	Mill scale (%)	Anthracite (%)	Binder (%)
	77.5%	12.5%	10%


Briquettes prepared with a samples of hydrochar powder or anthracite were used for melting tests (melting of the only briquette and addition to a melted iron bath).

In case of hydrochar use, neglegible carburisation has been obtained.

Conclusions

- ✓ Compared to the reference, the hydrochar has generally **higher volatile matters** content, that could be reduced with thermal pyrolysis

- ✓ The **briquettes react well** in the tests carried out, they have good reactivity, they do not cause problems in the melting process. Materials after HTC has good reducing capability, while material after HTC+pyrolysis has positive steel bath carburization capability. In case of utilization as charge material in the basket with scrap, material produced with HTC+pyrolysis is preferable. In case of injection should be evaluated with industrial trials.

- ✓ When the material is used in briquettes mix with rolling mill scale, there is no significant difference whether the hydrochar is in the form of powder or pellets

ESTEP
European Steel Technology Platform

Thank you for your attention!

Co-funded by the European Union

BioRe Steel

Authors*:*
Valentina Alemanno,
Daphne Mirabile,
Filippo Cirilli,

BioReSteel - Valorization of wet biomass residues for sustainable steel production with efficient nutrient recycling. RFCS project

Contacts*:*
valentina.alemanno@rina.org
daphne.mirabile@rina.org
filippo.cirilli@rina.org

The work described was developed thanks to the funding from the European Union, which is gratefully acknowledged. The sole responsibility of the issues treated in the present paper lies with the authors; the Union is not responsible for any use that may be made of the information contained therein.