The role of slags and other by-products within circular economy in the steel industry

- Current results on upgrading iron- and steelmaking by-products: the TransZeroWaste project
- Gerald Stubbe (VDEh-Betriebsforschungsinstitut)

5.–6. MARCH 2025

ESTEP Focus Group Circular Economy & FEhS-Institute

ESTEP
European Steel Technology Platform

INSTITUT FÜR BAUSTOFF FORSCHUNG
FEhS

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Initial situation, current and future materials & recycling requirements

- **Transformation to low-carbon steel industry**, from coal to H_2 as reduction agent to meet the European climate and energy targets (climate-neutrality by 2050)
- **Change of production units & routes**
  - Current: Sinter plant → Blast furnace → Basic oxygen furnace
  - After transformation: Pelletizing → Direct Reduction (DR) process → Electric arc furnace
- **Scrap-based EAF-route with no internal recycling and a major amount of landfill requirement**
  → *requirement to develop new recycling technologies* to avoid landfill and recuperate valuable raw material
- **Currently high (95 %) internal recycling within BF-BOF-route**
  → *further increase recycling with new technologies* to also enable recycling of the remaining 5 % (oily sludges and oily scale)
- **New transformation to low-CO_2 steel production via DR-EAF-route will cut-off the current high recycling of BF-BOF-route**
  → requirement to find recycling technologies to avoid landfill and recuperate valuable raw material
  → *gain knowledge of new types of "waste" with so far unknown composition/amounts and develop adapted new recycling technologies*
  → *enlarge the potential raw material basis for the DR-EAF-route by developing technologies that will allow use of low-grade ore*

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Main objectives of TransZeroWaste

- **Upgrading low-grade iron ore** by combining with iron-rich by-products
- **Development of innovative techniques to produce high quality pre-material** for decarbonised future production routes
- **Separation of disturbing components** from byproducts to replace scrap
- **Development of the technological basis and digital tools** supporting the transition towards zero waste in the European steel industry

-> Three main technical approaches

Typical material samples

Fraction from iron sieving | Coarse mill scale | Fine mill scale (oily contents up to 10 wt.-%)

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1st technical approach - Cold pelletisation and briquetting for direct use in existing and future steel works

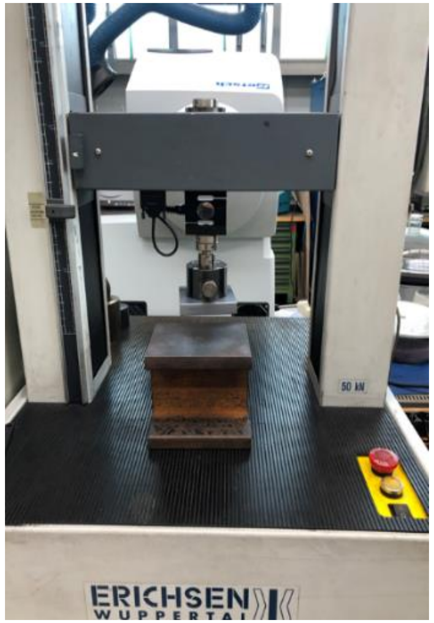
Process development for cold pelletisation, briquetting for use in direct reduction processes (e.g. shaft furnace)

Pelletisation

Produced pellets
(ca. 8 mm)

Optional:

Burning in muffle furnace
(1250°C; 20 min)



Compression test machine

Briquetting

Tablet press & Pressing parts
10 mm

Briquettes
10 mm

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1st technical approach - Cold pelletisation and briquetting for direct use in existing and future steel works

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Briquetting trials for screening of binders (13x)

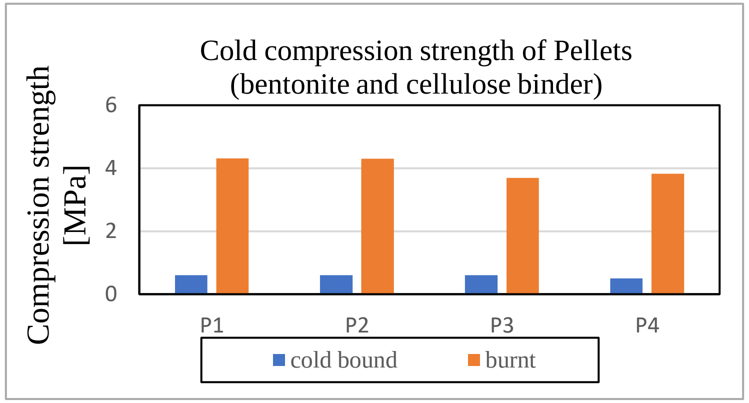
- Organic binders
- Cements and cementitious materials
- Inorganic Polymers

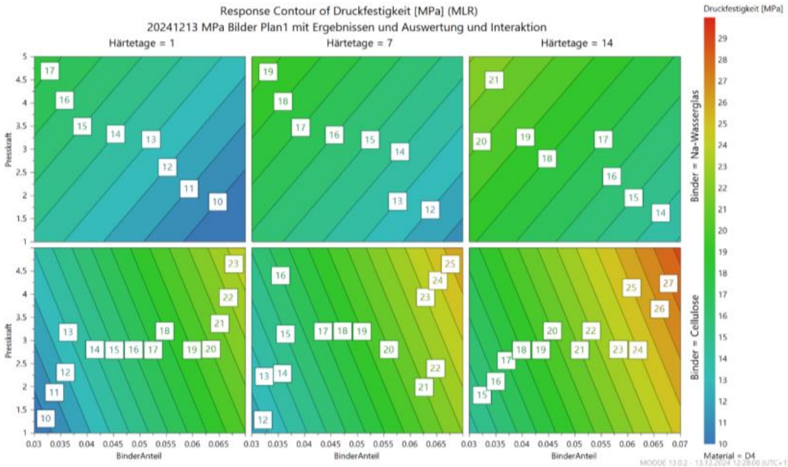
- Best performing binders (Briquetting)
  - **Sodium-waterglass (max. 37 MPa)**
  - **Cellulose (max. 30 MPa)**
  - **Bentonite (max. 27 MPa)**

Briquetting trials – software-based Design of Experiments (DoE)

- Two Residues; two binders…
- Highest influence on compression strength:
  - Binder type & amount (but reverse behaviour of cellulose and waterglass); Curing time; Pressing force
- Low influence:
  - Material type
- No significant influence:
  - Particle size distribution/grinding

Pelletising results





Briquetting results: Response contour diagram

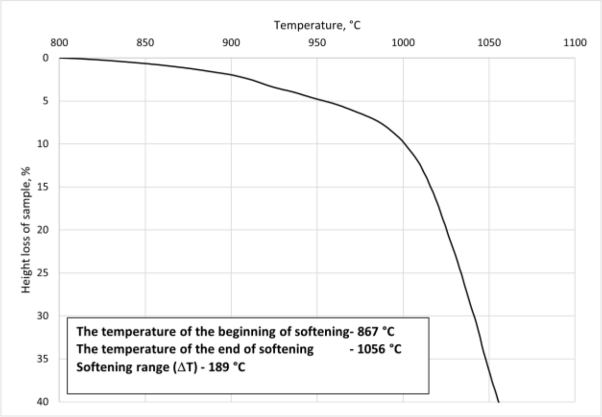
Main conclusions: Cold compressive strength of **briquettes** close to requirements of iron ore pellets (35 MPa); much lower strength for **pelletisation**, even after burning (< 5 MPa, too low even for material handling?)

Next steps: Continuation of trials for optimization of Briquetting and Pelletisation procedure and -mixes; Use of de-oiled mill scale sludge samples; Verification of lab results in technical scale and field trials (CSIC, CELSA)

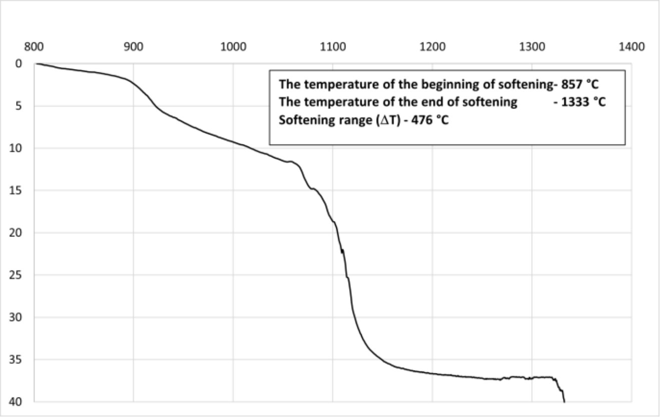
Hot tests of briquettes (GIT)

- **Thermoplastic properties**
- **TGA**
- **ISO 11258** (Iron ores for shaft direct-reduction feedstocks – Determination of the reducibility index, final degree of reduction and degree of metallization)

Thermoplastic Properties tests



Binder: sodium silicate



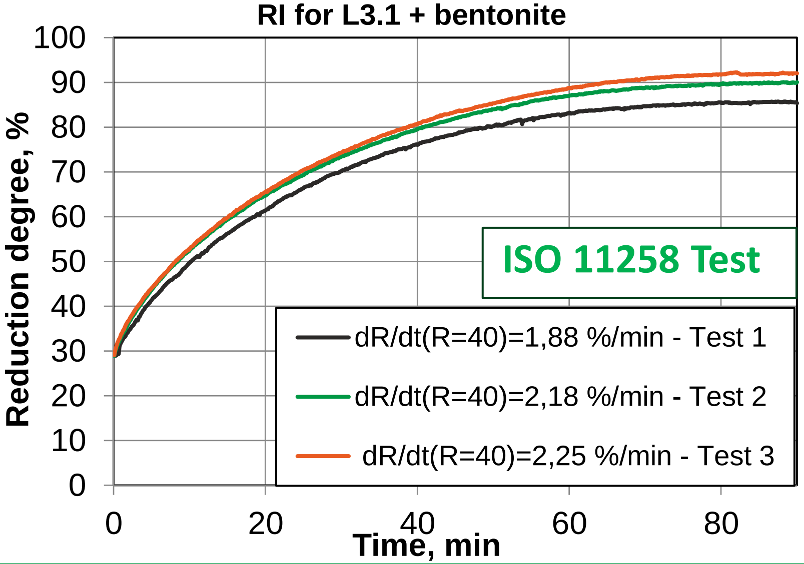
Binder: cellulose

Main results:

- *Wide softening range* for briquettes bound with cellulose -> disadvantageous for shaft furnaces
- Reducibility test: *Repeatability* of reduction degree needs to be improved

Next steps:

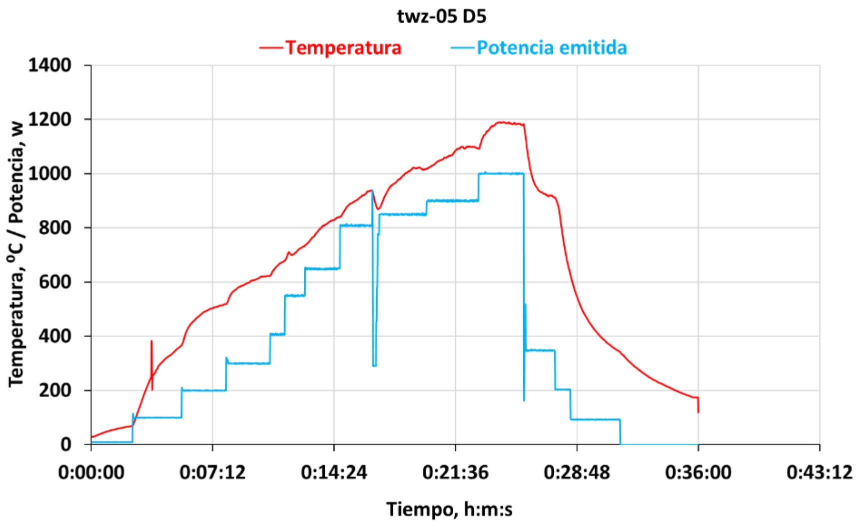
- Improvement of procedure is already ongoing (need to minimize material consumption); Continued hot tests



2nd technical approach - Hot pelletization with microwaves

Stationary Microwave trials

- Mixtures of samples to adjust the carbon content show good performance
- Reaction is taking place but is incomplete at T=1100°C
- Best iron extraction is obtained for T>1200 °C



Ref CNT	Mixtures	"Carbon content balance"	Result
1142+1158	**D1.1 + L3.2**	**35%**	**Iron + Ca-Fe**
1156+1160	**L2 + L7**	**31%**	**Free Iron**
1137+1141	**C2 + C1.1**	**29%**	**Free Iron**
1142+1263	D1.1 + E1.1	35%	No iron
1150+1151	**I1 + I2**	**7%**	**Free Iron**
1151+1152	I2 + I3	7%	No iron
1142+1146	**D1.1 + D5**	**24%**	**Free Iron**
	Mill+EAF		

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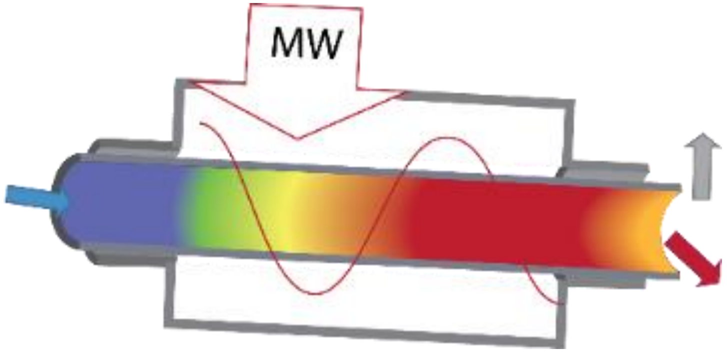
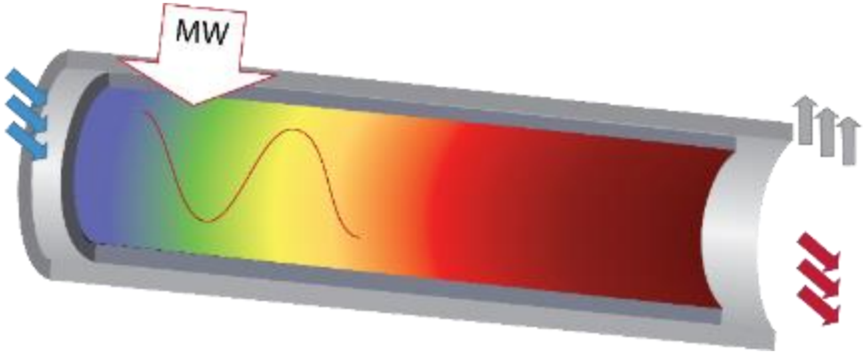
2nd technical approach - Hot pelletization with microwaves

Upgrade the hot pelletizing with microwaves

- Development of a new process using the *DESTINY microwave applicator concept* (CNT with support of BFI, K1, UPV)
- Development of a new concept of full integrated microwave applicator (CNT, UPV)
- Innovative microwave treatment concept for hot pelletizing supported by findings of pre-trial investigations for adaptation, optimization and further enlarged potential (CNT, UPV, DH)
- Demo trials will be performed at DH with CNT and BFI



DESTINY BASED
Ceramic tube crossing the MW cavity



TransZeroWaste UPGRADING
Metallic tube is the MW cavity

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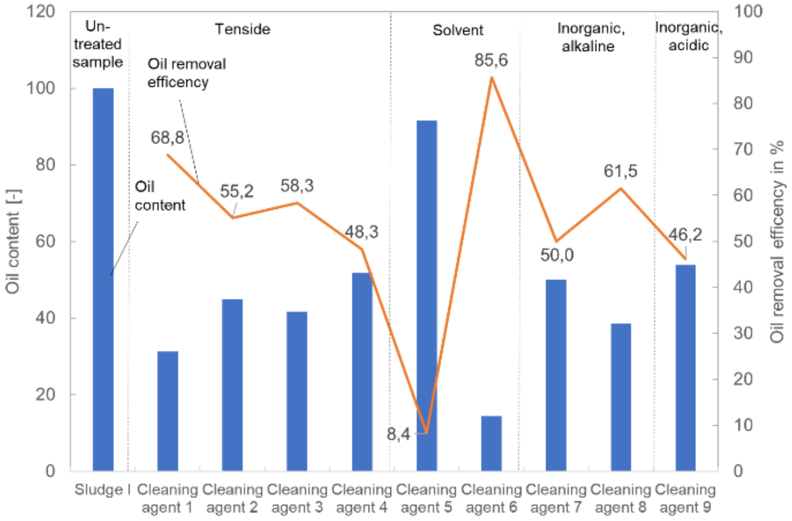
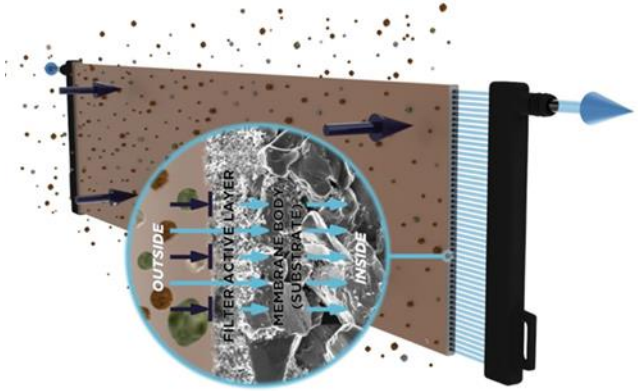
3rd technical approach - Hydro-metallurgical treatment for removal of impurities

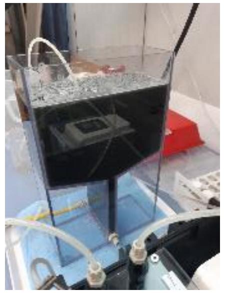
- **Hydrometallurgical pre-treatment** of residues with high iron contents e.g. oily sludges, which are currently disposed of or thermally treated due to the impurities
- **Transfer** of results to treatment of oily scrap
- **Approach:** Combination of **magnetic separation** and **deoiling** followed by cleaning agent recovery by **filtration with ceramic flat sheet membranes**

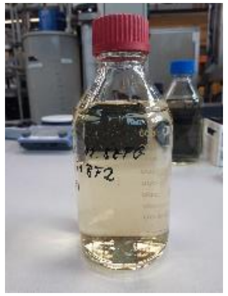


Selection of best performing cleaning agents



Cleaning agent recovery -> ceramic membrane filtration





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3rd technical approach - Hydro-metallurgical treatment for removal of impurities

Next steps:

Field trials at an exemplary site

- **Field trials – deoiling**
  - Preparation of test plants (BFI) and site location (CELSA) is ongoing
  - Installation of test plants and performance of field trial (BFI) supported by CELSA
- **Field trials – metallurgical reuse**
  - Briquetting/pelletising of deoiled material (amount: ca. 20 t)
  - Treatment in direct reduction reactor
  - Metallurgical reuse in of DR treated briquettes/pellets in operational electric arc furnace EAF at CELSA Barcelona site

Magnetic separator plant

Ceramic membrane filtration plant

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Further technical approaches & expected impacts

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Further technical approaches

- **Economic and Environmental Evaluation**
  - **Circularity indicator evaluation** for the TZW technologies
  - **Life Cycle Assessment** of the developed technologies
  - **Evaluation of the overall steel production** and support towards decarbonization targets
  - **Life Cycle Costing**
  - Integration of environmental and economic sustainability indicators into **decision-support tool** to facilitate the **identification of most sustainable processing routes**

Expected impact

- **Contribution to climate-neutral & circular industrial value chains** supporting transition towards low-CO_2 -DR and EAF production routes

  ➢ **TZW technologies aim to provide solutions on TRL 8 to fill the gaps for recycling & upgrading** for ore- and scrap-based green steel production

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