MIX DESIGN OF 3D-PRINTABLE CARBON-NEGATIVE CONCRETE RECIPES

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1. Introduction

The construction industry faces urgent demands to improve sustainability while addressing enduring labour shortages. Current energy-rooted approaches and material-intensive practices are increasingly misaligned with emerging environmental targets, such as the 2050 net-zero emissions. Consequently, a comprehensive upgrade to the sector's design philosophy and technological framework is both timely and essential.

This study employs a performance-based approach to innovate formations that;

- Incorporate 100% secondary constituents solely based on industrial slags (no cement and virgin aggregates)
- Are not hydraulically or alkali-activated
- Are 3D-printable
- Solely rely on mineral carbonation curing for full strength development
- Meet mechanical and durability performance criteria suitable for compression-dominant, deconstructable structures

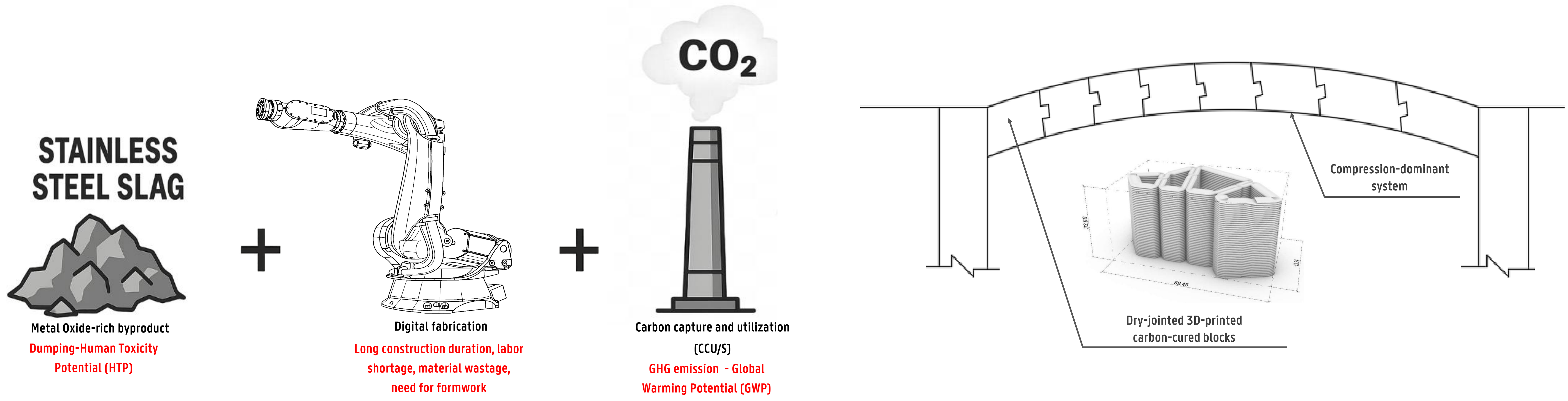

Fig 1: schematic idealization of the study framework

2. Materials and test matrix

- **Binder – Carbinox**

Fine stainless-steel slag fraction

Particle size: 0.25 mm max

- **Aggregates - Stinox**

Coarser blended slag fraction

Particle size: 2 mm max.

Aggregates and binder are supplied by Orbix, Belgium

- **Additives**

SP: Polycarbonate Ether Superplasticizer (BASF)

VMA: Hydroxypropyl Methylcelulose, Tylose (Shin-Etsu)

mix	A/B ratio	W/B ratio	SP/B ratio (%)	VMA/B ratio (%)
M-0.5_0.25	0.5	0.25	0.80	0.056
M-0.5_0.30	0.5	0.30	0.25	0.056
M-0.5_0.35	0.5	0.35	0.00	0.075
M-0.7_0.25	0.7	0.25	1.00	0.080
M-0.7_0.30	0.7	0.30	0.50	0.080
M-0.7_0.35	0.7	0.35	0.00	0.045
M-1.0_0.25	1.0	0.25	1.75	0.090
M-1.0_0.30	1.0	0.30	1.00	0.090
M-1.0_0.35	1.0	0.35	0.50	0.090

A/B - Aggregate-to-binder ratio
W/B - Water-to-binder ratio
SP/B - Superplasticizer-to-binder ratio
VMA/B - VMA-to-binder ratio

Mixing time, 2.5 min rotary mixer

Mix M-0.5_0.25 considered reference mix for the first 3D-print test, its performance reported here as key result.

3. Methods

Rheology Optimization
Flowability – ASTM 1437-20
Slow penetration tests

Printing of Small-scale Specimens
Automated 2D mortar gun.

Carbonation Curing of Specimens
Carbonation chamber (3% CO_2, 20˚C Temp, 60% RH)

Mechanical Performance Assessment
Compression and flexural strength tests

3D Print Trial
Reference mix 3D-printed - 6-axis robotic arm

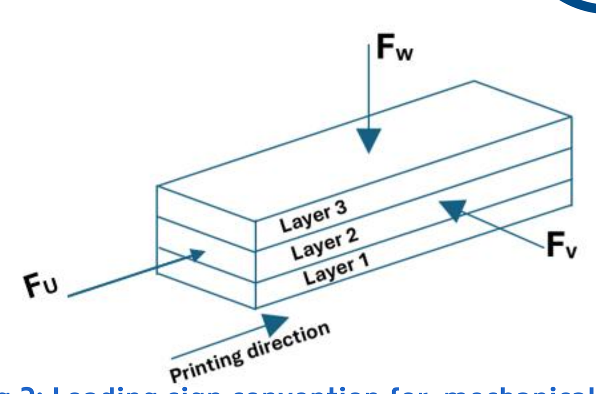

Fig 2: Loading sign convention for mechanical testing

4. Key results

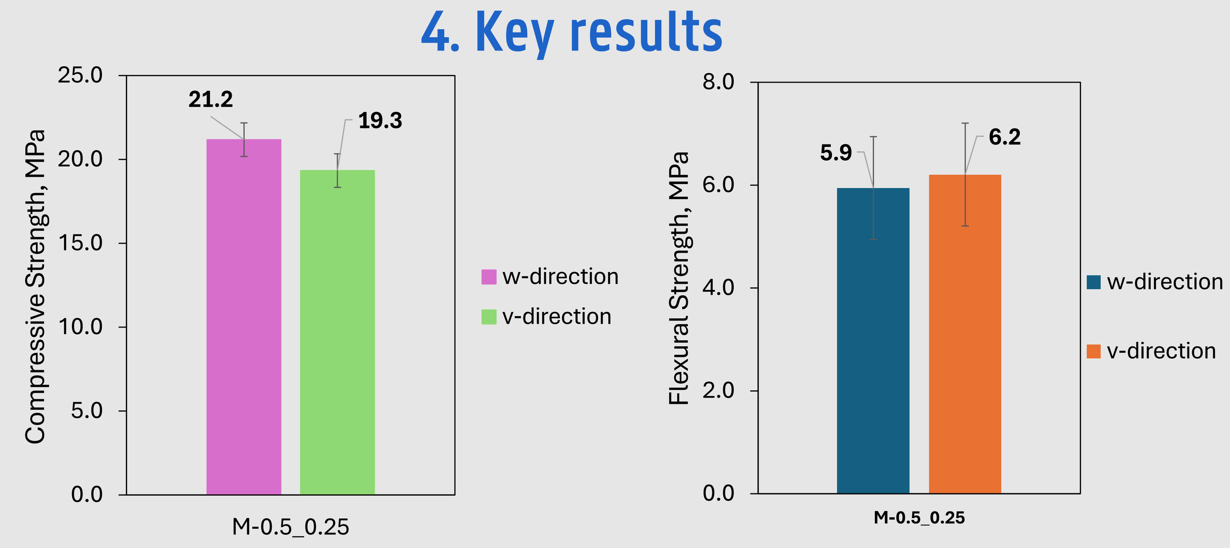

Fig 3: Mechanical performance

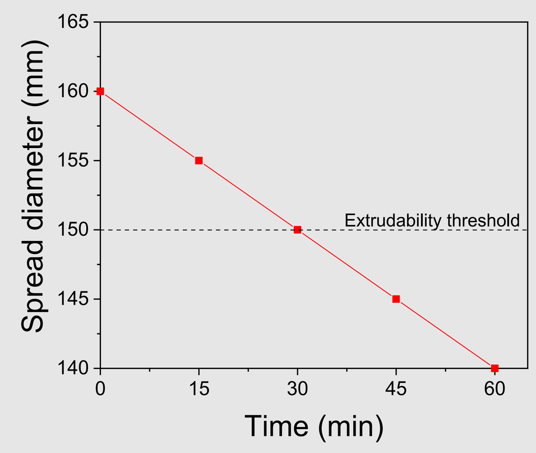

Fig 4: Flow retention

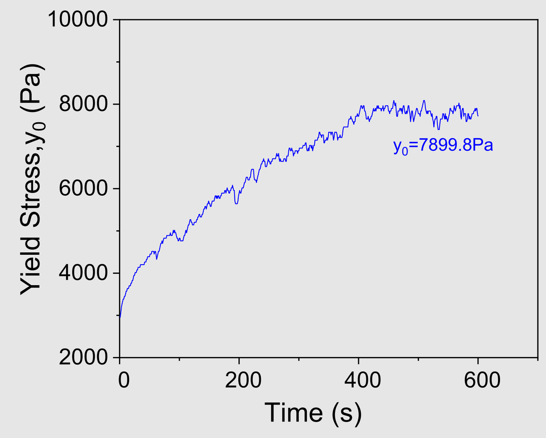

Fig. 5: Yield stress evolution

Fig. 6: First 3D-printing test

Fig. 7: 3D-printed & carbon-cured block

5. Conclusions

- **Flow optimization** enabled achievement of a printable rheology using **non-activated industrial slags** with additives
- Achieved up to **22 MPa compressive** and **6 MPa flexural strength** after **7 days of carbonation curing** (3% CO_2, 20˚C Temp, 60% RH)
- successful **first 3D-print trial** with **one-component (1k) system**
- ✅ **Demonstration of potential for ultra-low-carbon waste-based materials in 3D concrete printing (3DCP).**

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