Additive Manufacturing in Construction
1st Funding Period: The Challenge of Large Scale

AMC TRR277

A02

Particle-Bed 3D Printing by Selective Cement Paste Intrusion (SPI) - Particle Surface Functionalisation, Particle Synthesis and Integration of WAAM Reinforcement

Prof. Dr.-Ing. C. Gehlen, T. Kränkel, A. Straßer
Prof. Dr.-Ing. A. Kwade, H. Zetzener, L. D. Hamilton
Prof. Dr.-Ing. M. F. Zaeh, S. Baehr, Felix Riegger

Chair of Material Science and Testing (cbm), TUM
Institute for Particle Technology (iPAT), TUBS
Institute for Machine Tools and Industrial Management (iwb), TUM

Project summary

This project aims to enable the selective paste intrusion (SPI) for practical applications. Therefore, reinforcements are implemented in SPI parts by using wire arc additive manufacturing (WAAM). The main challenge for the combination of WAAM and SPI is the high temperature caused by WAAM.

Main outcome of 1st funding period

- Particle size distribution and packing density affect SPI concrete strength significantly.
- Passive cooling by functionalised particles is feasible but challenging.
- WAAM reinforcements achieve comparable properties to conventional reinforcements.
- The heat induced into the reinforcements by WAAM can be reduced with sprayed water or compressed air.
- Limitations of integrating WAAM into the SPI system (e.g., nozzle distance and temperature load) are identified.

Production cycle of SPI with WAAM

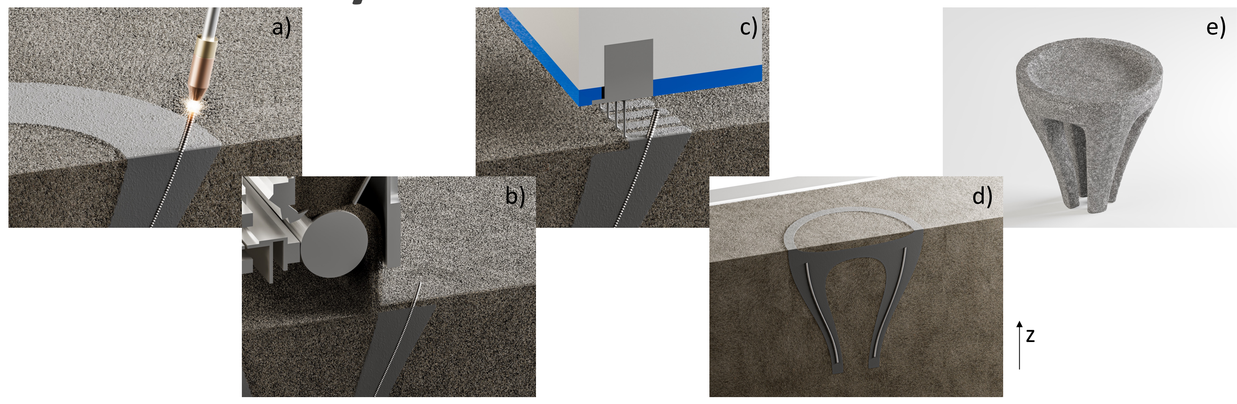

Fig. 1: Process steps of SPI with WAAM; a) printing a rebar, b) spreading of an aggregate layer, c) depositing the cement paste, d) finished structural component, e) excavated component; z: building direction

Key collaborations in 1st funding period

- A01 Exchange on particle functionalisation
- A03 Exchange on cement paste and rheology
- C02 Shape-optimised structures for A02
- A05 Exchange on fiber reinforcement
- A07 Exchange on WAAM
- C03 Development of insulation for SPI structures for A02

Project status

Selective Paste Intrusion:

- Acceleration of the SPI process through the implementation of a multi-nozzle print head.
- Parameter and print settings for protruding reinforcement bars and increased distances between nozzle and particle bed were figured out (strategy for passive cooling).

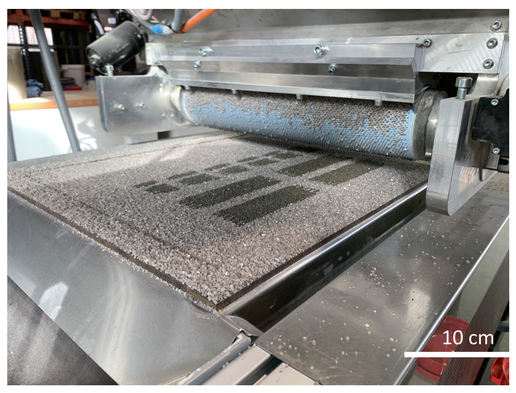

Fig. 2: SPI printer during the production of specimens

Tailoring and functionalisation of aggregates in the particle bed:

- Dry water is implemented for cooling purposes.
- The stress model is applied for the process description (mixture quality).
- Water storage and passive cooling with sufficient bulk properties is possible.

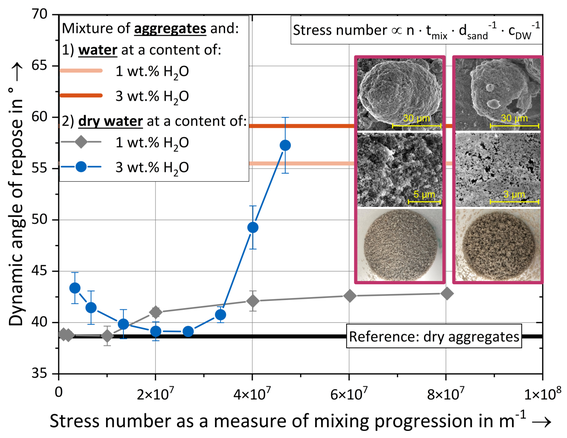

Fig. 3: Effect of dry water and process parameters on the flow properties of otherwise cohesionless sand with the dynamic angle of repose as a measure of the mixture flow properties

The effect of various aggregate particles on the SPI concrete strength:

- Dry water in the currently used form decreases the concrete strength.
- The SPI concrete strength increased with a bimodal aggregate size distribution.
- Minimal amounts of water are necessary to prevent segregation.
- A further improvement of the packing density is difficult with the current process limitations.

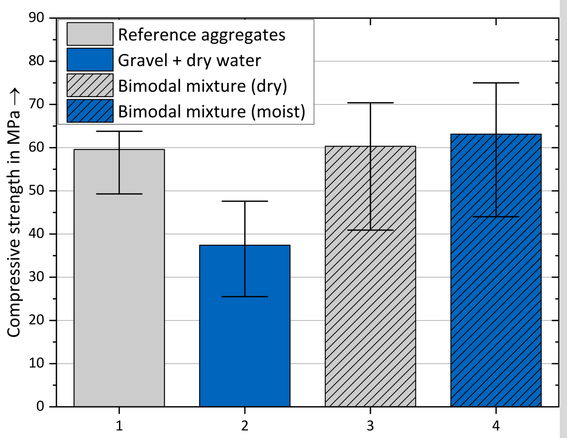

Fig. 4: Influence of particle mixtures (i.e., size distribution and additive) on concrete properties

Wire Arc Additive Manufacturing:

- The printability of reinforcements with WAAM was validated through experiments and simulation.
- Strategies for the production of 3D reinforcement structures were developed.
- The reinforcement bars reach temperatures of up to 204 °C during WAAM at a distance of 40 mm to the process zone.

Investigations on SPI + WAAM:

- WAAM reinforcements show a good bond behaviour with concrete.
- Tests of the bond strength of specimens produced with temperature load are pending.

Large-scale printer:

- The large-scale portal printer is under construction.
- Experiments with SPI + WAAM with the new portal printer will be conducted in the 2nd half of 2023.

Fig. 5: Parameter study on WAAM nodes

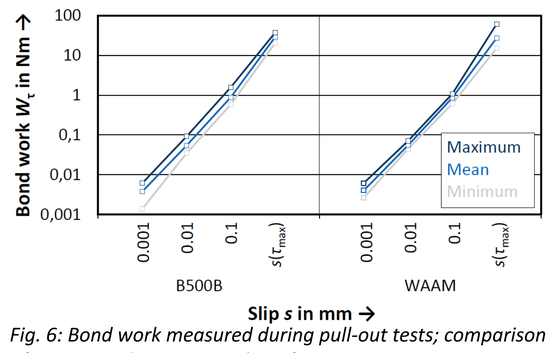

Fig. 6: Bond work measured during pull-out tests; comparison of WAAM and conventional reinforcements

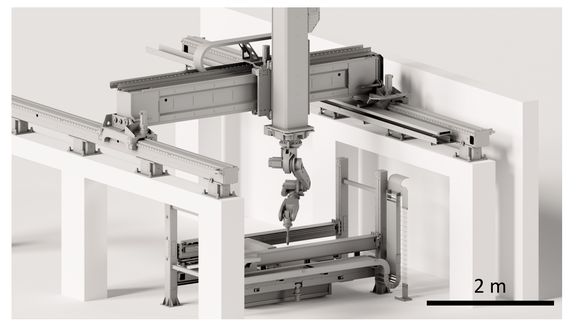

Fig. 7: Portal for combined SPI + WAAM printer

Collaborative demonstrator

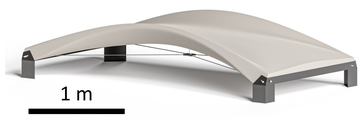

Fig. 8: Bridge the gap

Bridge the Gap

- The concrete elements for the bridge were built with SPI. The elements can be used as-built.
- The post-tensioning node was produced with WAAM.

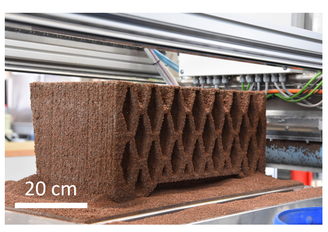

Fig. 9: Playing with blocks

Playing with Blocks

- Thermal and mechanical properties of SPI components with expanded clay were investigated.
- Wall elements with cavities filled with unbound expanded clay were optimised for thermal insulation and produced with SPI.

Funded by
DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Technische Universität Braunschweig
Technical University of Munich