Final Report

Project acronym: *BauProAddi*
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Publishable project summary

The joint project "BauProAddi" focused on developing innovative, printable concretes and realising a high-quality and cost-effective additive production process in the construction industry. The project emphasis was on material development, which makes the desired additive production process possible in the first place. Due to the cooperation of various companies, universities, and research institutes throughout the value chain, an innovative, automated, fast, flexible, and precise manufacturing technology was developed.

In particular, a large number of inorganic binders were designed, characterised, and optimised. These included materials based on Portland cement (ordinary and under-sulphated), alkali-activated materials, and super-sulphated ground granulated blast furnace slag binders. To achieve an optimum setting behaviour for additive manufacturing, plenty of binder compositions – especially varied calcium sulphate contents – and addition of accelerating admixtures were investigated. For evaluation of the hydration and the resulting setting, following techniques were applied: Vicat needle as well as new-developed penetration test, ultra-sonic P-wave propagation, spread flow, one-dimensional shrinkage, measurements of mechanical strength (at a few minutes of age but also standardised ages), isothermal conduction calorimetry, scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy, (in-situ) X-ray diffraction, thermodynamic modelling, performance tests of additive manufacturing and some other.

Materials with a reduced ecological footprint have been developed by reducing the cement clinker content. Cement clinker in the developed printable materials was replaced by supplementary cementing materials such as fly ash, ground, granulated blast-furnace slag and silica fume, which are all waste products of industry. Further printing materials based on super-sulfated slag cements and geopolymers have been developed using in maximum 5% or even no cement clinker at all. A multipurpose incremental loading device (MILD) was developed, which enables precise analysis of early strength development of fast-setting materials. This device can work in compression and penetration mode on very young samples, which enables a comprehensive analysis of the early structural build-up in the material being fundamental, especially for additive manufacturing.

A concept of a model-based planning method for AM was developed, which will enable potential clients to have the full control of the components being constructed and the cost of the construction. As a reliable parameter in calculating the cost of a 3D printed object, the price per printed meter has been identified as this parameter can be implemented in the calculation software. Concerning the normative compliance of 3D printed objects, the experimental approach has been identified as more promising.

Another critical point was the implementation of additive manufacturing into already existing and highly developed processes on construction sites. Tunnel construction and especially the application of shotcrete in tunnel construction has been identified as one possibility to implement AM already soon. As precise process control is crucial in additive manufacturing concerning, e.g., the printing velocity, Doka is currently developing different systems to analyse the setting behaviour of cementitious materials in situ on the construction site. The measurement of IR-radiation and the electric conductivity have been identified as suitable measurement methods and have now to be adapted onto the specific needs of AM. Profitability analysis showed the potential of additive manufacturing to enter the broad market.

Regarding the development of different printer concepts, it can be reported that a 6-axis robot equipped with a controllable printing outlet developed within the project to meet the needs of AM (e.g., precisely controlled material deposition) and a material delivery system which was adapted to the requirements of additive manufacturing (continuous mixing of dry and wet material components and continuous supply of material with constant viscosity parameters) has been installed.

Several portal printers (3 axes) and delta printers have been installed. A form inventory has been developed considering the process particularities of 3D printing, such as the possibility to produce components of high complexity (e.g., integration of functionalities such as cable ducts), while at the same time avoiding right angles, which are hard to realize in a continuous AM process. Concepts of designing a software environment in which the 3D model of the component to be printed and the machine code dynamically interact are improved continuously.
Different objects have printed at several places with the printers, as mentioned above. These objects were in the range of cm- to m-scale and showed the considerable potential of 3D printing for generating object hardly or not at all possible by other ways of manufacturing.