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# EVALUATION OF THE PROPERTIES OF CEMENTITIOUS COMPOSITE SUITABLE FOR 3D PRINTING

## ABSTRACT

The idea of speeding up the construction process by means of automation may revolutionize the whole civil engineering. The 3D printing of cementitious materials is a technology that allows for additive manufacturing of complex building structures at shorter time and lower material usage compared to traditional construction. Over the last eight years, the number of research teams and commercial companies dealing with the subject of 3D printing in construction has grown exponentially. The main problem of this technology is to design a composite with appropriate properties. The cementitious concrete mix designed for additive manufacturing should maintain its properties during the printing. The fresh concrete mix immediately after extrusion must retain its shape under its own weight and load from subsequent layers. Furthermore, the printed material formed by the nozzle shall not be deformed during the printing process. The precise determination of such parameters of the mix is one of the main research topics in this field.

Another important problem is to assess the strength of the printed structure. The 3D printed structures must transfer loads from slabs, lintels and other elements, and the time after which it can be done should be precisely determined. The evaluation of the strength of the printed composite must also take into account possible temperature changes that may occur on the construction site. For this purpose the maturity method can be used.

The problems presented above are not fully recognized. The automation in construction by means of additive manufacturing is to this day still relatively scarcely researched. Currently, there are no standardized research methods to assess the suitability of a mix for 3D printing. In addition, there is no function to assess the load-bearing capacity of the concrete mix that can be used to optimise the printing process. In the context of a hardened composite, there is no maturity method to assess its compressive strength under varying thermal conditions.

The theoretical part of this dissertation describes the printing methods, basic principles and the selected implementations for 3D printing (chapter 3). A detailed analysis of properties and research methods relevant for printed mixtures were described (chapter 4). In addition, the current state of knowledge about the maturity method and the possibility of its application to assess the strength of cured composites created by additive manufacturing is described (chapter 5).

The research can be divided into three stages (Chapters 6 - 11). The first stage included preliminary tests of mixtures with potential application in 3D printing. For this purpose, several structures were printed at different output parameters. The parameters were evaluated in several categories. On this basis, preliminary properties of mixtures intended for printing were determined.

In the second part of the preliminary tests, 24 mixtures were tested on a simple printing stand, of which eight were selected for further testing. The second stage of research included thorough tests of eight selected mixtures. The properties of the mixes and hardened composites were determined in detail. Each of the mix was tested at nine different times, which allowed to determine the development of mechanical parameters of the mix. The mechanical properties of cured composites were determined under variable thermal conditions, which allowed to apply the maturity method. The method was used to derive the functions determining the development of strength over time.

The third stage included verification consisting in printing selected mixtures at several different times. The relationship between the strength of the mixture obtained in the preliminary tests and the actual print was then determined. At this stage, destructive tests of printed structures were performed. After the tests, an analysis of the results was carried out (Chapter 12) and functions defining mechanical properties of the mixture and the hardened composite were derived (Chapter 13).

Based on the research carried out in this dissertation, an original method of evaluating the mixtures applicability in 3D printing was developed. A function has been developed which, by using required target structure's parameters as input data, calculates the recommended printing speed. The existing maturity functions were changed in such a way that it is possible to use them to assess the strength of the printed composite after hardening. The research showed a number of relationships between the composites tested, which are presented in the summary (Chapter 14).

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