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THE EFFECT OF CURING ON SHRINKAGE DEFORMATION OF CEMENTITIOUS COMPOSITES USED IN 3D PRINTING TECHNOLOGY - *ABSTRACT*

The 3D printing with cementitious materials is one of the fastest growing industry branches in the world. Its main advantages are the possibility of shortening the time of construction, reducing material consumption and use of human resources. The idea of 3D printing, called additive manufacturing, is based on successive stacking layers of material using computer-controlled robots. It enables to produce complex 3-dimention structures. The use of cement based mixtures as the material for printing creates opportunities to use such technology also in the construction sector. Over the last 10 years, the number of research teams and commercial companies interested in 3D printing with use of cementitious mixtures has begun to grow exponentially. The increased interest has been a catalyst for many research works that have focused on the durability aspects of additively manufactured elements.

One of the many still unsolved problems is the issue of proper curing of cement-based composites printed structures. Most of the available literature addresses this issue in a superficial way or only recommends further research in this area. The issue of curing is crucial due to the lack of traditional formwork used in traditional concrete construction to protect the fresh material from rapid moisture loss. The lack of this barrier can lead to cracking and reduced strength of the completed elements, which can result in lower durability and the need for expensive repairs.

This dissertation attempts to critically evaluate external and internal curing methods possible to apply in the context of 3D printing technology. The literature review can be divided into 3 main sections. The first section (Chapters 3 and 4) discusses the key aspects of 3D printing technology using cementitious materials. The most relevant scientific publications were cited, the commonly used research methods were analyzed, and various 3D printing techniques were described, distinguishing their capabilities and limitations. The second part (Chapter 5) deals with concrete shrinkage. It analyzes the latest literature on the subject, systematizes the nomenclature and evaluated the measurement methods currently being used by research teams. The third part (Chapter 6) is devoted to the discussion of curing mechanisms and ways of preventing shrinkage deformations. The dissertation refers to national and foreign standard guidelines for typical concrete structures and their applicability in the context of 3D printing technology.

The conducted research, along with the analysis of the obtained results, is presented in Chapters 7-13. The first stage of the research refers to the selection of a suitable mixture for 3D printing, as well as determining the influence of modifications of the composition on the main rheological parameters of fresh material. Specially designed tests were conducted for each mix to determine its suitability for printing. The initial compressive strength of the fresh mixture, which is responsible for the ability to carry the weight of subsequent printed layers in the plastic state, was evaluated. The pumpability and cohesiveness of the mix were also analyzed. The print quality, dimensional stability of printed samples or susceptibility to material discontinuity were evaluated. All the mixtures were subjected to standard strength tests and

total shrinkage was determined. In addition, an original method for measuring the total shrinkage of printed parts using non-contact laser technology was proposed. This method allowed continuous measurement of the material deformation both in the plastic state and after setting. The analysis resulted in selection of the best mix for the next stage of testing taking into account influence of various curing methods on composite.

As part of the basic research, the effect of the geometry of the adopted specimens on the values of measured strain in the author's laser method was evaluated. The effect of external constraint on the development of shrinkage was compared and its time-development was analyzed. Afterwards, the methods of internal curing, external curing and the possibility of modifying the composition were critically analyzed. Their effects on both material shrinkage and rheological and mechanical parameters of the composite were evaluated. The obtained results were compared with analytical models of shrinkage prediction.

The conducted research and analysis have shown that it is possible to reduce the shrinkage of printed parts using traditional methods of curing, however most of them do not show sufficient effectiveness. The usefulness of the proposed method for measuring the shrinkage of printed components has been confirmed and the underestimation of shrinkage in existing analytical methods for its prediction has been demonstrated. Detailed conclusions, along with proposed further research directions, are presented in Chapters 14-17.

21.04.2023

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