Proceedings of the 32nd Nordic Seminar on Computational Mechanics
A.H. Niemi and H. Koivurova (Eds.)

Mathematical modelling of sustainable bioresidual concrete

Tero Tuovinen[1], Teemu Leppänen[1] Joni Parkkonen[2], Jussi Virkajärvi[2], and Leena Turunen[3]

(1)University of Jyväskylä, Faculty of Inf. Technology, {tero.tuovinen, teemu.e.leppanen}@jyu.fi
(2)University of Jyväskylä, Department of Physics, {joni.parkkonen, jussi.virkajarvi}@jyu.fi
(3)Jyväskylä University of Applied Sciences, School of Technology, leena.turunen@jamk.fi

Summary. In the production of cement, which is the main component of concrete production, the process generates about 5% of the global carbon dioxide emissions. In addition, bioproduct and pulp mills produce significant quantities of soda ash and bio-ash, which is still largely unused. In this paper we will introduce our study related to improving the environmental friendliness of concrete used in construction by utilizing pulp mill waste while its long-term durability and strength and porosity properties meet the goals set for construction. The project 'sustainable bioresidual concrete' is on-going and only preliminary numerical results with measurements are presented here.

Key words: Concrete, Mathematical modelling, Sustainability, Carbon dioxide, Finite element method

Introduction

The aim of the project is to improve the environmental friendliness of concrete used in construction by using pulp mill waste while its long-term durability and strength and porosity properties meet the goals set for construction. In the project we will produce test pieces of concrete mixed in various ways, including cement, water, sand, ash and green liquor dregs (GLD). Concrete samples and their required strength and porosity properties are measured in both the JAMK's (Jyväskylä University of Applied Sciences) Concrete Technology Laboratory and by utilizing X-ray microtomography device of the Department of Physics at the University of Jyväskylä. In addition, samples and material and behavioral models are built on JYU's (University of Jyväskylä) Faculty of Information Technology to help optimize processes and sustainability.

One of the most important raw materials in construction is still concrete. While other forms of construction, such as wood and steel construction, are gaining in popularity, the application of these types of construction is much smaller than that of concrete construction. However, concrete as a building material is problematic; the production of one of its key components, cement, is environmentally harmful; it is estimated that 5% of the world's anthropogenic carbon dioxide emissions come from cement production. To prevent this, additives are used in the concrete, such as coal ash (= fly ash) and paper sludge as a waste-based source of calcite in cement [1].

The bio-ash and soda ash produced by the forest industry are not suitable for direct use as a concrete component. This has posed challenges for the recovery of forest industry waste in the construction industry. The project will result in a resource efficient way of utilizing the waste described above as a raw material and / or mixer for concrete. Studies show that fly ash improves many of the properties of concrete and reduces the amount of cement needed. Preliminary studies have also shown that the use of bio-ash and soda ash can improve the properties of concrete with respect to some criterias. The challenge so far has been considered due to variations in the composition of these waste fractions.

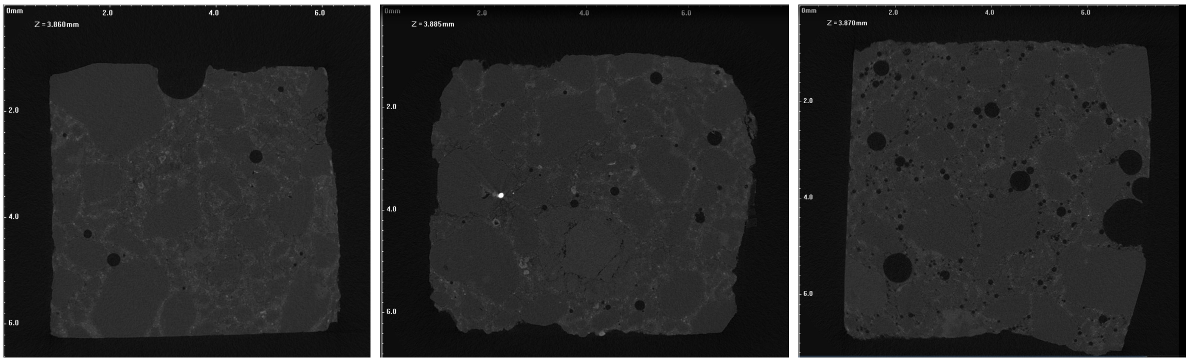

Figure 1. Cross sections from the concrete samples including 0% (left), 5% (center) and 10% (right) bio-ash.

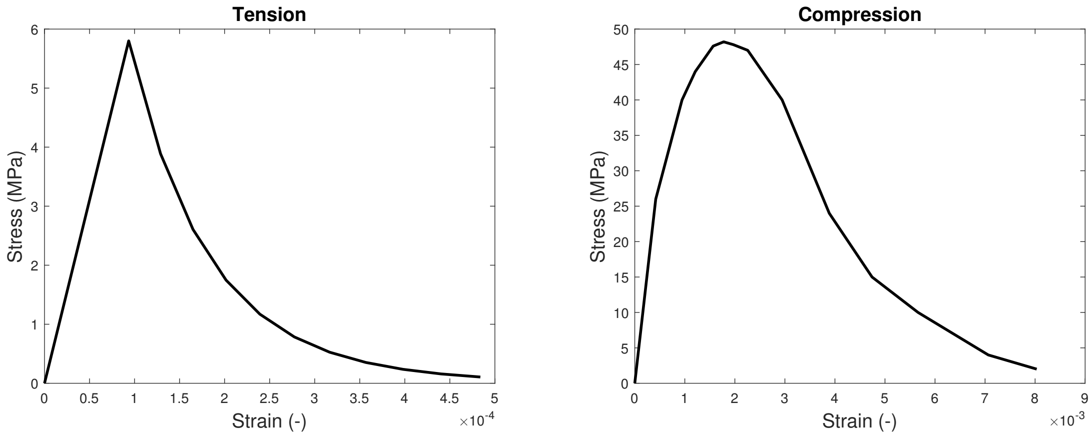

Figure 2. Material model for tension (left) and compression (right).

Concrete strength problems have been encountered especially in various infrastructures. One cause of the strength problems is the porosity of the concrete, which has caused, in particular, a decrease in compressive strength. Compressive strength is the most important strength property of concrete. However, the relationship between the porosity of concrete and its compressive strength is complex and has been extensively studied. However, at present, there are reliable mathematical models which can be used to predict the relationship between the porosity of a concrete and its strength; the main factor in the modeling is the pore size, and in particular the pore size distribution, which can be used to determine its effect on concrete strength.

Mathematical modelling of the case

X-ray tomography is used to reveal the structure of the samples having different amount of bio-ash, see Fig. 1. The size of the measured samples is roughly 5 mm×5 mm×5 mm. The pore size distributions are defined and used as a base structure of various sized simulation samples. Material model (Fig. 2) used in the simulations is based on typical behavior of concrete [2]. An example of simulated behavior under z-directional compressional stress is presented in Fig. 3. The developed model will be validated with respect to the data obtained and separate compression and/or endurance measurements. Once the model and the numerics involved in solving it are at a reliable level, multi-objective optimization can be initiated for a variety of material contents and uses.

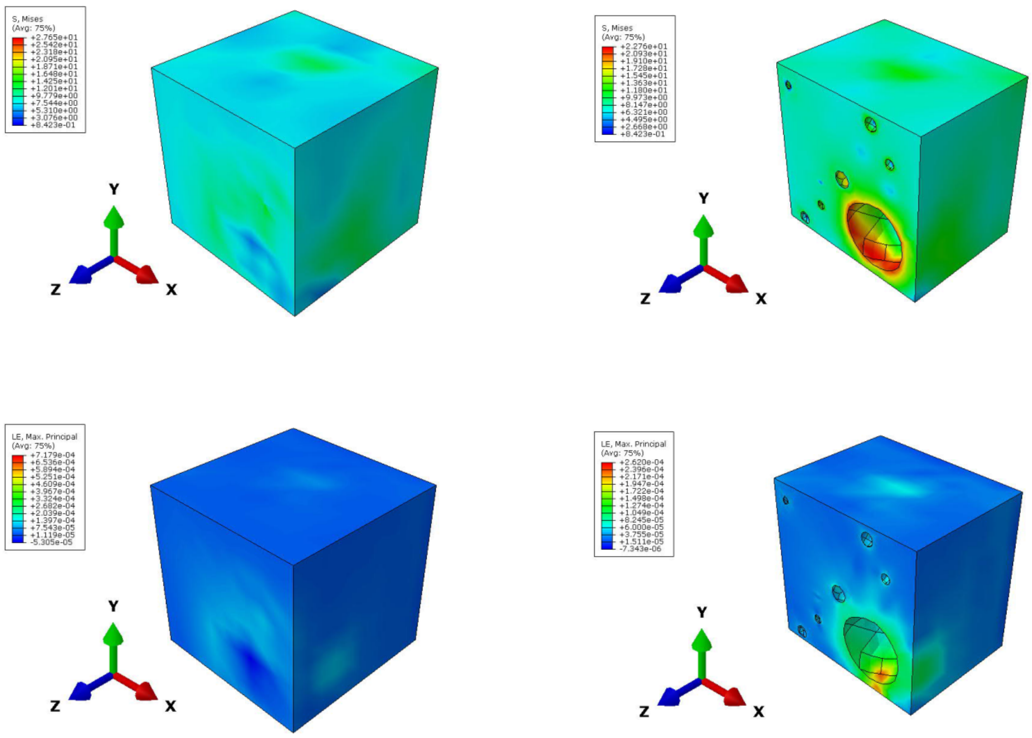

Figure 3. Simulated von Mises stress (top row) and maximum principal strain (bottom row) during the concrete damage under z-directional compressional stress. Size of the simulated sample is 0.5 mm×0.5 mm×0.5 mm.

Conclusions

In this paper, we have introduced the process model we use in mathematical modeling of biodesidual concrete and in strength and durability analyzes. Our aim is to produce more environmentally friendly concrete for the construction industry and to eliminate problematic soda ash from the paper and board industry.

Acknowledgements

This research is supported by Regional Council of Central Finland and European Regional Development Fund (ERDF) - Sustainable Bioresidual Concrete. Simulations are performed by commercial software ABAQUS which is licensed to CSC (the Finnish IT center for science).

References

[1] E. Adesanya, K. Ohenoja, T. Luukkonen, P. Kinnunen, M. Illikainen *One-part geopolymer cement from slag and pretreated paper sludge* Journal of Cleaner Production 185 (2018) 168-175.

[2] C.G. Koh, M.Q. Teng, T.H. Wee *A Plastic-Damage Model for Lightweight Concrete and Normal Weight Concrete* International Journal of Concrete Structures and Materials 2 (2008) 123-136.