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MATERIAL PARAMETERS OF CEMENT AND ALKALI ACTIVATED FLY ASH CONCRETE MIXTURES LABORATORY MEASUREMENTS AND NUMERICAL SIMULATION

M. Šejnoha, * M. Brouček, ** E. Novotná, * D. Lehký, † P. Frantík, ‡ Z. Keršner †‡**

Abstract: *The paper reports on the determination of basic mechanical material parameters of several concrete and alkali activated concrete and fly ash mixtures intended for the construction of segmental lining used in TBM tunneling. The results of an extensive experimental program are discussed first. The principal attention is accorded to the experimental determination of specific fracture energy, which, when compared to numerical simulations, shows certain inconsistency with the measurements of other material data. This is supported by the derivation of the data from inverse analysis employing the elements of soft computing.*

Keywords: ***Alkali activated fly ash, Concrete, Fracture energy, Finite element simulation, Soft computing.***

Massive increase of CO_2 emission in recent years has supported a considerable effort towards the substitution of ordinary Portland cement by alkali-activated aluminosilicate materials such as fly ash in the production of concrete. Using fly ash as admixture in cements is now common in many applications. Full substitution for large scale structural units, however, is still at its infancy and to foster its progress beyond laboratory samples will require fundamental understanding of what is occurring already on the level of paste during alkali-activation process.

Tab. 1: Material properties obtained experimentally

Notation	Elastic modulus	Compressive strength	Transverse tension strength	Fracture energy
	E [GPa]	$f_{c,cube}/f_{c,prism}$ [MPa]	f_t [MPa]	G_f [N/m]
C	38.5	84.7 / 72	4.4	207.4
FiC	39.5	78.0 / 65	3.7	-
FAC	40.1	66.3 / 59	3.1	190.9
FiFAC	39.7	61.3 / 63	3.1	-
POP	18.9	36.2 / 28	2.9	112.3
FiPOP	20	39.5 / 30	2.9	-

This topic, however, goes beyond the present scope. Instead we focus our attention on the macroscopic evaluation of the response of various mixtures of concrete and alkali-activated materials with emphases on the influence of fly ash replacing either a certain portion or an entire amount of cement. We

*Prof. Ing. Michal Šejnoha, Ph.D., DSc.: Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7; 166 29, Prague; CZ, e-mail:sejnom@fsv.cvut.cz

**Ing. Miroslav Brouček, : Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7; 166 29, Prague; CZ, e-mail:miroslav.broucek@fsv.cvut.cz

***Ing. Eva Novotná, Ph.D.: Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7; 166 29, Prague; CZ, e-mail:novotnae@fsv.cvut.cz

†Ing. David Lehký, Ph.D.: Brno University of Technology Faculty of Civil Engineering Veveří 331/95 602 00 Brno;CZ, e-mail:lehky.d@fce.vutbr.cz

‡Ing. Petr Frantík, Ph.D.: Brno University of Technology Faculty of Civil Engineering Veveří 331/95 602 00 Brno;CZ, e-mail:kitnarf@centrum.cz

†‡Doc. Ing. Zbyně Keršner, CSc.: Brno University of Technology Faculty of Civil Engineering Veveří 331/95 602 00 Brno;CZ, e-mail:kersner.z@fce.vutbr.cz

consider both experimental and numerical part of this research effort as these should be considered on the same footing to mutually corroborate the obtained results.

Summary of the experimental work appears in Table 1. The following notation is introduced to distinguish individual mixtures: C - Cement based concrete (reference mixture), POP - Alkali-activate fly ash, Fi - mixture containing fibers, FAC - mixtures with partial replacement of concrete by fly-ash. While cubic specimens having edge length of 150 mm were used to measure strength properties ($f_{c,cube}$, f_t), 300 × 150 × 150 mm prisms were manufactured to acquire the values of Young's moduli. These specimens were further utilized to provide the uniaxial compressive strength $f_{c,prism}$. A particular attention was dedicated to the determination of fracture energy from a three-point bending test. Three notched specimens for each mixture having dimensions 150 × 150 × 700 mm with a notch depth of 25 mm were tested in a displacement-controlled loading regime at the rate of 0.05 mm/min up to 0.2 mm of crack mouth opening displacement (CMOD) and at the rate of 0.2 mm/min until failure. All measurements were performed 28 days since the time of their production.

Tab. 2: Material data of ATENA 3D Non Linear Cementitious 2 model for two concrete specimens C1/C2

Parameter	IDTE Mesh-TE	IDNN Mesh-NN
Elastic modulus [GPa]	48 / 55	82* / 96*
Poisson's number [-]	0.2	0.2
Tensile strength [MPa]	3.8 / 4.5	2.7* / 2.9*
Compressive strength [MPa]	72	72
Specific fracture energy [N/m]	70 / 60	228* / 206*

The results for two particular concrete specimens from associated numerical simulations focused on the representation of three-point bending test with emphases on the identification of specific fracture energy are stored in Table 2. The ATENA FEM code was adopted. Both simple trial and error method (1st column in Table 2) as well as more rigorous Artificial Neural Network (ANN, Lehký and Novák (2009), 2nd column in Table 2) based identification method were exercised. Parameters labeled with (*) were subject to identification. Note that different meshes were considered for the two approaches, unstructured relatively coarse Mesh-TE and regular fine Mesh-NN. Clearly, while the Young's moduli and tensile strengths received in the first case only minor adjustment if compared with the measured values in Table 1, the specific fracture energy required a significant reduction to match measured and simulated loading curves reasonably close. On the contrary, referring to G_f values identified in the second approach we observe a good agreement with the values provided by experiment. However, the identified values of Young's moduli are unrealistically high compared to the measured ones.

In overall, both approaches revealed unreliability in the direct use of experimentally measured values of fracture energy as a material parameter. Most probably, this could be attributed to the applied rate of loading, which should be at least 10× smaller to comply with the assumption of static analysis. This issues will be the subject of further research. Attention also deserves a considerable dependence of the results of simulations on the finite element mesh promoting similar mesh coarseness used in lab experiments and structural simulations at least in areas prone to damage evolution.

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