OVERALL PROPERTIES OF FRC COMPOSITES FROM RECYCLED MATERIAL: RANDOMLY DISTRIBUTED FIBERS

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Introduction

Since any recycling is greatly appreciated by the human community also in the field of fiber reinforced concretes (FRC). The paper informs professional community about the state of the art in production of FRC from building and wrecking waste aggregates in the Czech Republic and about numerical models applied to assess the structural elements from such composites. First certain results from experiments with used components are shown and then the mathematical model is briefly mentioned. Description of material properties starts from extended Hashin-Shtrikman principles leading to boundary element method, [1]. This trick is applied to the problem of debonding in composites in [2] and deterministic approach is derived. The idea of stochastic evaluation of composites is due to the publication [3]. The results from the latter paper is used in [4] for finite element solution. Here a non-trivial extension to the boundary elements is suggested.

Experimental

First in Fig. 1 the total production of recycled FRC in the Czech Republic is depicted.

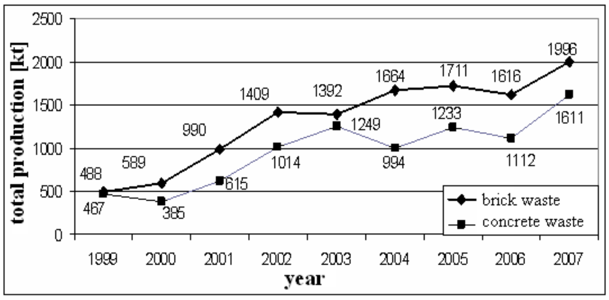

Fig. 1 Total production of recycled brick and concrete waste FRC in the Czech Republic

Figs. 2, 3, 4 show the fiber properties, where
C7H: Fibers FORTA FERRO, more recycled aggregate
C8H: Fibers FORTA FERRO
C9H: Fibers BENESTEEL
C10H: No fibers
C11H: Carbon fibers

In Fig. 5 a force-deflection diagram of one typical composite is shown. This is involved in description of non-linear behavior (plasticity, residual stress).

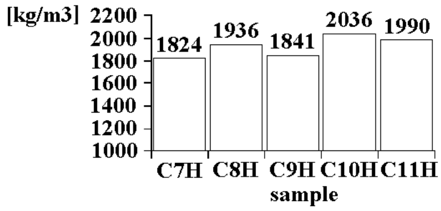

Fig. 2 Volume weight: average of 6 samples

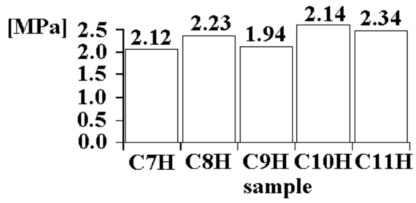

Fig. 3 Transversal tensile strength: average of 5 samples

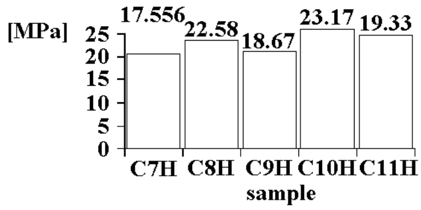

Fig. 4 Approximate compressive strength of 1 cube

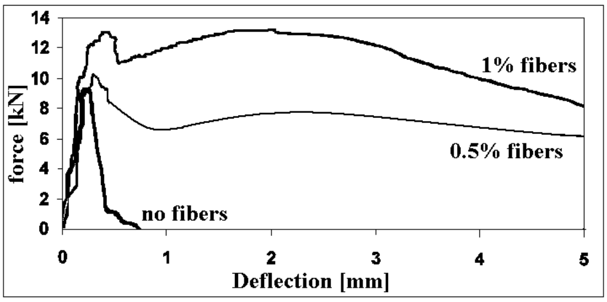

Fig. 5 Force-deflection graph of recycled FRC withForta Ferro fibers.

Randomly distributed phases

Let the fibers be randomly distributed in the composite medium. Denote by α the individual phenomena in a sample space S. The probability density of α in S is defined by $\mathrm{d}(\alpha)$. The characteristic function $\kappa_r(\xi,\alpha)$ is equal to 1 when ξ lies in phase r and 0 otherwise. Then the probability $P_r(\xi)$ of finding the phase r at ξ is the *ensemble average* of $\kappa_r(\xi,\alpha)$; i.e., [3],

$$P_r(\xi) = \int_S \kappa_r(\xi,\alpha)\,\mathrm{d}(\alpha) \tag{1}$$

The two-point probability of finding simultaneously the phase r at ξ and the phase s at x is defined by

$$P_{rs}(\xi) = \int_S \kappa_r(\xi,\alpha)\kappa_s(x,\alpha)\,\mathrm{d}(\alpha)\mathrm{d}(\alpha) \tag{2}$$

Further we assume the material to be statistically uniform; consequently ergodic assumption can be introduced. Extended H-S principles, [1], leading to introduction of comparative medium and stochastically burdened polarization tensor, provide new H-S principles in terms of stochastic variables, [5]:

$$\begin{aligned} U &= U^0 - \\ &-\frac{1}{2}\sum_{r=1}^{n} c_r \int_{\Omega} \tau^r(x)[(L_r - L^0)^{-1}\tau^r(x) - 2\varepsilon^0(x)\,\mathrm{d}\Omega(x)] \\ &+\sum_{r=1}^{n}\sum_{r=1}^{n}\int_{\Omega}\int_{\Omega} \tau^r(x)\tau^r(\xi)\Gamma(x,\xi)P_{rs}(x,\xi)\,\mathrm{d}\Omega(x)\mathrm{d}\Omega(\xi) \end{aligned} \tag{3}$$

where U^0 is the energy of the comparative medium, x,ξ are the positions of phases, c_r is the volume ratio of r-phase, τ^r is the polarization tensor of r-phase, L_r is the elastic tensor of r-phase, L^0 the stiffness of the comparative medium and ε^0 its strain field, and Γ is approximate and integrated energy:

$$\begin{aligned} \Gamma(x,\xi) &= \varphi^*(x,\xi) - \\ &- \int_{\partial\Omega} H^*(x,\xi)N(x)U^{-1}E^*(x)\,\mathrm{d}\partial\Omega \end{aligned} \tag{4}$$

where the quantities with asterisk are integrated known kernels, N are the base functions (linear splines), U is the matrix arising directly from boundary element method belonging to unknown displacements. The Euler equations easily follow form (3), see [5].

Example

Since the above preposition is put forward, the probability $P_r(\xi) = c_r$ and the main problem consists in finding the two-point probability. This is done according to the recommendation of [4], i.e. the cubes are cut and binary image is prepared the two-point probability from which is derived. This can be carried out at each state of loading. For linear stage of the material resulting overall stiffness tensor is listed below for $c_{fiber} = 1.5\%$.

Method	L_{11}	L_{22}	L_{12}	G
BEM	16.38	16.38	2.63	4.82
One fiber	16.39	16.39	2.61	4.81
Three fibers	16.37	16.37	2.62	4.82
Mori-Tanaka	16.37	16.37	2.62	4.82

Tab. 1 Material properties of composite

Conclusions

The paper is focused on application of brick and concrete waste to preparation of FRC. The waste serves a new type of aggregate. Large extent of experiments has been carried out to get concretes, which are mostly used in reinforcement of soil. Their tensile strength basically increases due to a reasonable choice of fiber types. In order to have good information for assessment of such composites stochastic method is suggested in this paper and a methodology of design in proposed. It appears that from the theoretical point of view proper agreement in results is attained and the internal input data can be obtained from tests conducted on standard samples

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References

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