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Fracture Mechanics Parameters as Criteria for Use of Mortars

Paramètres de la mécanique de rupture comme critères d'application

Parameter der Bruchmechanik als Anwendungskriterien von Mörtel

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SUMMARY
Research has been carried out on cement matrix mortars and on fibre-reinforced mortars. The materials tested were of very different microstructures. Both standard and fracture mechanics parameters have been measured. The strong relationship between the microstructure and fracture behaviour of the materials has been observed. Unfortunately, on the basis of the results obtained, it seems impossible to improve all the material characteristics simultaneously.

RÉSUMÉ
La contribution présente les recherches sur les mortiers de ciment et sur les mortiers de fibres. Les matériaux examinés se caractérisaient par une microstructure fortement différente. On a déterminé les propriétés traditionnelles de ces matériaux ainsi que les paramètres de la mécanique de rupture. Il existe une étroite relation entre la microstructure des matériaux et les mécanismes de rupture. Les résultats des essais ont montré qu'il n'ést malheureusement pas possible d'optimiser simultanément toutes les caractéristiques sur un même échantillon.

ZUSAMMENFASSUNG
En wurden Untersuchungen durchgeführt an Zementmörteln und an faserbewehrtem Zementmörtel. An den einzelnen Probekörpern von sehr unterschiedlicher Mikrostruktur wurden die klassischen Materialeigenschaften und die Parameter der Bruchmechanik untersucht. Es besteht ein enger Zusammenhang zwischen der Mikrostruktur eines Zementmörtels und seinem Bruchverhalten. Die Versuche haben aber auch gezeigt, dass es leider nicht möglich ist, an einem Prüfkörper alle Materialeigenschaften gleichzeitig zu optimieren.

1. INTRODUCTION

In hitherto civil engineering practice a standard procedure, based mainly on measurements of compressive and flexural strengths, has been used for assesment of properties of cement matrix structural materials. The higher and higher service demands on materials subjected to cyclic or dynamic loads has caused that new research procedures and techniques were seeked for to enable an estimation of their structural applicability by means of fracture toughness parameters. As a result, numerous efforts were undertaken in order to transform brittle fracture mechanics methods developed and tested for glass, ceramics and metals to the area of brittle concrete-like materials [1].

This paper reports on results of a research program designed to answer a question if it is possible to model microstructures of cement pastes and mortars in such a way that both their standard strength and fracture tougness are high.

2. MATERIALS

The research has been carried out on cement matrix composites of maximum aggregate size 2.5 mm and on fibre reinforced mortars. The materials were of different amount and size of aggregate, kind of stone /quartz, basalt/, porosity, water-cement ratio and kind of fibres /steel, plastic/. Table 1 containes mix proportions and the other microstructural data of the materials tested.

3. TESTING TECHNIQUES

Standard and fracture mechanics parameters of materials tested have been obtained by the following means:

- flexural strength, R_g,: cuboids 0.04x0.04x0.16 m, 0.10 m span;
- compressive strength, R_s,: halves of the broken cuboids;
- Young's modulus, E, and Poisson's ratio, ν,: ultrasonic method;
- critical stress intensity factor, K_{Ic},: 3-point bending of notched beams, Instron 1126 testing machine; [2]
- fracture surface energy, γ_f,: Davidge-Tappin method [3];
- subcritical crack growth velocity, v,: double torsion method, 0.01x0.09x0.16 m plates with initial notch and groove; the $v=AK_I^n$ relation has been assumed [4].

Fracture mechanics parameters of brittle materials enable to work out diagrams of their service lives and to design proof tests that can eliminate, before the real application in service, all the specimens that contain flaws of diameter too long to let the material work under the service stress for a desired period [5]. Fracture mechanics parameters of materials tested are given in table 2.

4. RESULTS

4.1 Flexural strength

Within the range of the materials tested it is noticable that the higher the porosity and an amount of aggregate the lower the flexural strength. This decrease is more intensive for the mortars of uniform sizes of sand. For 60% amount of sand the highest flexural strength is observed for a standard mortar containing quartz aggregate of 0÷2.5 mm size. Fibres substantially increase the flexural strength of mortars.

No.	Mix proportions aggr.	w/c	Density g/cm^3	Porosity %	E 10^{10} J/m^2	ν	Admix.
1	standard	.5	2.20	8.4	4.3	.34	-
2	-	.3	1.91	8.7	3.1	.33	-
3	-	.4	1.67	15.0	2.1	.20	-
4	-	.5	1.60	16.7	1.6	.26	-
5	-	.5	1.06	21.5	.7	.20	Al powder
6	fq12	.4	2.01	11.5	2.9	.27	-
7	fq30	.4	2.06	15.4	3.1	.30	-
8	fq60	.5	2.11	16.8	3.2	.32	-
9	mq60	.5	2.24	14.0	3.1	.33	-
10	cq12	.4	2.02	13.6	3.8	.33	-
11	cq30	.4	2.09	12.6	4.0	.36	-
12	cq60	.5	2.20	10.6	4.3	.37	-
13	fb12	.4	2.02	15.1	3.0	.26	-
14	fb30	.4	2.03	18.5	3.1	.27	-
15	fb60	.5	2.09	22.5	3.4	.28	-
16	cb12	.4	1.96	14.6	4.0	.34	-
17	cb30	.4	2.15	13.6	4.3	.35	-
18	cb60	.5	2.32	12.9	4.8	.36	-
19	standard	.53	2.27	10.88	4.3	.33	steel fib.
20	—"—	.53	2.24	10.11	4.3	.33	plast.fib.
21	standard basalt	.53	2.49	11.21	4.3	.34	steel fib.

Tab.1 Mix proportions and microstructural data of mortars.
f-fine /0-.5mm/, m-mean /.5-1.0mm/, c-coarse /1.0-2.5mm/
q-quartz, b-basalt, 12,30,60-average volume amount of sand /%/.

No.	R_g MPa	R_s MPa	K_{Ic} MNm$^{-3/2}$	γ_f Jm^{-2}	n	S_n	-logA	S_A
1	8.6	35.2	.64	12.8	9	12	57	8
2	11.9	52.1	.52	6.3	9	6	56	4
3	9.1	45.0	.44	2.2	15	6	87	5
4	7.7	36.1	.45	1.8	19	7	110	5
5	2.8	10.4	.21	9.6	-		-	
6	11.9	53.0	.66	6.4	11	8	68	7
7	10.2	42.6	.58	11.0	6	10	39	9
8	5.5	31.3	.44	13.1	6	15	49	13
9	5.7	30.1	.58	23.2	-		-	
10	9.8	50.9	.54	11.9	20	10	119	8
11	9.0	56.2	.56	23.5	17	13	102	11
12	6.6	42.5	.48	30.0	10	20	62	15
13	11.5	53.0	.72	15.6	18	11	110	8
14	10.2	50.3	.69	18.2	6	15	40	13
15	5.7	42.0	.65	21.1	27	22	159	18
16	10.4	55.7	.66	19.4	30	11	177	9
17	9.8	68.1	.62	31.5	11	18	68	15
18	7.6	43.7	.69	73.8	6	24	40	22
19	14.5	38.7	1.44	670.0	-		-	
20	7.5	33.3	.63	70.0	-		-	
21	12.5	52.0	1.36	540.0	-		-	

Tab.2 Standard and fracture mechanics parameters of mortars.
S-mean standard deviation /%/

4.2 Compressive strength

Compressive strength of the mortars decrease with the increase of porosity and a volume shear of fine aggregate. Materials containing coarse aggregate exhibit their maximum compressive strengths at about 30% vol. amount of sand. The highest compressive strength /68.1 MPa/ has been obtained for a mean size coarse aggregate mortar /30% vol./. Addition of fibres does not substantially increase the compressive strength of the mortars.

4.3 Young's modulus

Young's modulus of the mortars decrease with the increase of porosity and slightly increase with the increase of the volume shear of sand.

4.4 Fracture mechanics parameters

K_{Ic} decrease with the increase of porosity of the materials.tested. The higher the amount of fine quartz sand the lower the K_{Ic}, while for the basalt aggregate the influence of the volume changes of sand seem negligible. It is clearly visible that in all cases basalt aggregate effects in higher K_{Ic} values than the quartz sand. Admixture of steel fibres /1.5% vol./ increase the K_{Ic} values of the mortars of 110% /see No.19, No.21/. Fracture toughness of the materials /assesed by means of n and -logA/ increase with the porosity. The highest toughness exhibit the mortars of low w/c ratio, high percentage of microporosity and of coarse basalt aggregate at about 10% vol. /No.16/. Effective fracture surface energy γ_f decrease for the lower values of porosity and considerably increase for the higher porosities /No.2-No.5/. The increase of volume amount of all the kinds of aggregates increase γ_f. This effect is clearly visible for the coarse basalt grains. Admixture of steel fibres /1.5%vol./ effects in the increase of γ_f from 12.6 J/m^2 to 670 J/m^2.

5. CONCLUSIONS

On the basis of the results obtained it is possible to establish a relationship between the mortars' microstructures and their standard mechanical properties. For the micro-concretes K_{Ic}, n, -logA and γ_f can be considered the materials' constants describing their toughness to subcritical crack growth and to impact damage. The best way to increase the fracture toughness of the cement matrix materials is to increase the values of K_{Ic}, n and -logA. Within the range of materials tested attempts to model the microstructures of the mortars in order to obtain the highest possible values of all the three parameters simultaneously have failed. For the cement composites subjected to cyclic loads the optimalization of their microstructures should increase the values of γ_f. Unfortunately, it is a difficult process because generally the microstructural parameters that are responsible for the high γ_f values decrease both R_g and K_{Ic}.
Application of the cement matrix materials for any specific working conditions, along with flexural and compressive strengths, should take into account the fracture mechanics parameters, still bearing in mind the necessity of a deliberate compromise between all the materials characteristics.

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