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ON QUANTITATIVE FRACTOGRAPHIC ANALYSIS OF HIGH DENSITY CONCRETES

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ABSTRACT

Fracture toughness tests in mode II for dense concrete with the w/c (water to cement) ratio varying from 0.6 to 0.9 were reported. Profile lines of fractured concrete specimens underwent independent, dual quantitative analysis: using image analyser Quantimet 720 and tablet digitizer coupled with an IBM PC personal computer. The results of fracture toughness tests were compared to fracture profile line parameters. It was demonstrated that the R_L–K_{IIc} and R_L–J_{IIc} relations evaluated for ordinary concrete were not valid for dense concrete (R_L denoted linear roughness, while K_{IIc} and J_{IIc} denoted fracture toughness).

Keywords: dense concrete, fracture toughness, quantitative fractography, surface topography.

INTRODUCTION

Advances in quantitative fractography resulted in new methods of broad and general application in experimental analysis of structure–property relationships. However, quantitative fractography seems to be applied rather in the field of metallography or ceramics than in cement matrix materials (Banerji 1988, Coster and Chermant 1983, Cwajna et al 1984, Stang et al 1990, Stroeven 1990, Stroeven and Babut 1986, Underwood and Banerji 1987). Only a few works have been devoted to fracture properties of dense concrete designed for radiation shields in atomic structures (Jamroży and Rawicki 1991, Rawicki 1990,1991). Concrete radiation shields are among the most important structures in civil engineering and fracture toughness is one of their fundamental characteristics. It may play an important role as well in normal service conditions when local microcracks can emerge as in the case of any accidents.

Taking into account the basic properties of brittle bodies it has been assumed that shear stresses are more dangerous than compressive stresses. The above mentioned assumption was taken as a basis for planning and carrying out the tests on special dense concrete envisaged for construction of the shield for an atomic reactor vessel (Rawicki 1990). The aim of the present work is to analyse the possible relation between fracture toughness and fracture surface morphology of these concrete.

EXPERIMENTAL PROCEDURE

Fracture properties of the concrete tested were characterised using the following quantities: critical value of the stress intensity factor in mode II, K_{IIc}, critical value of the J–integral in mode II, J_{IIc}, number of fractured through grains per unit test area N_A' and mean area of fractured through grains $\bar{a}$. Fracture toughness tests were carried out according to the concept proposed by Prokopski (1989) on cube–shaped specimens with two notches described by Watkins (1983).

The concrete for tests was composed of the following fractions: Portland cement "45", 0/4 mm Brazilian iron ore with apparent density of 4.99 g/cm^3, 4/16 mm Brazilian ore pellets with apparent density of 4.97 g/cm^3 and 0/8 mm rolling mill scale with apparent density of 5.25 g/cm^3. Weight composition of the concrete is given in Table 1. Different batches were prepared using w/c ratio in the range from 0.6 to 0.9 (step 0.1).

Table 1. Composition of concrete (kg/m^3)

rolling mill scale	pellets	Brazilian iron ore	water
1535	1270	290	(0.6–0.9*cement

The same series of specimens: 3 cubes 15 cm side for compression tests and 12 cubes 15 cm side for fracture toughness tests were cast from each type of test concrete. Two different types of notches were introduced:

a) by cutting hardened concrete using a diamond saw (6 specimens) and

b) by inserting steel blades in a mould where specimen was cast (6 specimens).

The specimens were cured during the first 7 days in water and stored in laboratory conditions during subsequent 21 days. Such prepared specimens underwent laboratory tests.

Fracture surfaces and profiles were analysed using image analyser Quantimet 720. Fracture profiles were also analysed independently with the help from an IBM PC computer coupled with the Summa Sketch MM1200 tablet digitizer (suitable program prepared independently by L.Wojnar). Profile lines were prepared in the following way: on the basis of fractured specimen a PVC replica was prepared using emulsified PVC E–68. Emulsified PVC enabled good reproducibility of subtle details in fracture surfaces with no bonding with this surface. Additionally, thanks to their excellent elastic properties, PVC replicas were easy to remove from fracture surfaces and subsequent cuts did not introduce any deformation to the profiles obtained. Each replica was cut perpendicularly to the macroscopic fracture surface. From each replica 12 slices were prepared and used subsequently as typical rubber stamps to produce precise, highly contrasted profiles on paper sheets.

Quantitative analysis of profiles was performed using the following parameters: 1 pixel=0.119 mm (Quantimet) and Dx=0.39 mm (digitizer, stable x–increment). The parameters measured are shown in Table 2. In order to enable precise digitisation all the profiles were enlarged 4 times using typical Xerox copier.

Table 2. Quantitative parameters of fracture profiles
(Underwood 1987, Wojnar 1990)

parameter	method
linear roughness, R_L	Quantimet, digitizer
maximum roughness height R_{max}	Quantimet
mean profile height deviation R_a	digitizer
mean roughness height, h	digitizer
mean radius of curvature, r	digitizer

RESULTS AND THEIR ANALYSIS

All the experimental results are shown in tables: fracture and mechanical properties in Table 3 and quantitative fractographical data in Table 4. Analysis of the results revealed that there exist close relation between the w/c ratio and fracture toughness. The best toughness was obtained for w/c=0.6 and it decreased monotonically with the increasing w/c.

Comparison of the fracture toughness data for various types of notches showed that concrete with w/c=0.6 gave higher fracture toughness for specimens with cut notches whereas in case of w/c=0.7, 0.8 and 0.9 higher values were obtained for specimens with notches formed by steel blades. So, for w/c between 0.6 and 0.7 the notch formation type did not affect fracture toughness.

Table 3. Mechanical and fracture properties.

w/c	0.6	0.7	0.8	0.9
apparent density (kg/dm^3)	3.53	3.51	3.50	3.48
compressive strength (MPa)	30.1	26.1	18.6	15.9
K_{IIc} (formed notch) ($MN/m^{3/2}$)	3.83	2.63	2.58	2.45
K_{IIc} (cut notch) ($MN/m^{3/2}$)	4.67	2.55	2.38	2.28
J_{IIc} (formed notch) (N/m)	1890	1410	1390	1210
J_{IIc} (cut notch) (N/m)	2820	1180	1070	1050

It is clear that the increase in w/c ratio is correlated with the decrease in number and mean area of grains fractured through. For w/c=0.6 and 0.7 higher area of fractured grains was observed for specimens with formed notches.

Analysis of profiles showed that there is no clear dependency between linear roughness and fracture properties. This remark is valid for all the w/c values and both types of notches. Prokopski (1989) noticed for ordinary concrete that K_{IIc} was proportional to the linear roughness (R_L). In our study this remark was not confirmed for dense concrete. The opposite tendency was recognised: decrease in R_L whereas K_{IIc} increased. It was probably connected with the fracture mechanism. In case of quasi–plastic fracture (w/c=0.9) the crack grew through the matrix, without cutting aggregate grains. It caused more complicated and curved fracture surface.

Table 4. Morphological parameters of fracture surfaces

w/c	0.6	0.7	0.8	0.9
results from Quantimet 720				
a (formed notch) (mm^2)	405	293	127	124
a (cut notch) (mm^2)	291	240	180	159
N_A' (formed notch) (dm^{-1})	8.5	7.4	4.8	3.6
N_A' (cut notch) (dm^{-1})	10.5	9.6	5.7	3.6
R_L (formed notch)	1.14	1.17	1.15	1.20
R_L (cut notch)	1.18	1.23	1.16	1.13
R_{max} (formed notch) (mm)	14.2	13.8	10.2	11.8
R_{max} (cut notch) (mm)	18.0	24.4	11.7	15.0
results from IBM PC and digitizer (formed notches only)				
R_L	1.11	1.12	1.11	1.15
R_a (mm)	5.1	5.37	4.06	3.78
r (mm)	11.58	12.76	14.76	10.83
h (mm)	13.7	14.5	15.8	11.7

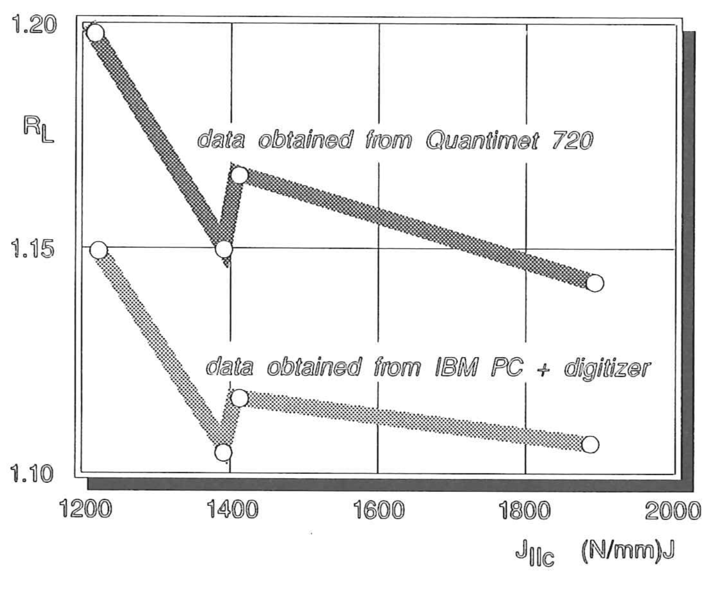

Fig.1. Profile line parameters versus work of fracture

CONCLUSIONS

1. The w/c ratio highly affects fracture properties of dense concrete. Best properties are for low w/c=0.6 (due to technological requirements lower w/c values were not tested).

2. Quantimet 720 and IBM PC coupled with tablet digitizer give similar results when evaluating profile line parameters. However, the same resolution of profile line is required for both methods.

3. A close relation between linear roughness and fracture toughness existing in ordinary concrete is not valid for dense concrete.

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