BEHAVIOUR OF HIGH-STRENGTH CONCRETE AT HIGH LOADING RATES

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Abstract

Cracks in plain concrete run along the boundary layer of the concrete-aggregate grain. The aggregate grains are pulled out from the surrounding cement paste under friction. This friction, which shows a partial viscous character, leads to an additional force transfer in the composite material at high rates of loading. In contrast, in high-strength concrete under low rates of loading, the cracks run right through the aggregate grains, due to of the hardened cement paste and the improved bond between the cement paste and the aggregate. This leads to relatively smooth crack-surfaces and also to a small toughness of the high strength concrete. Additionally for a high strain rate, the viscose friction of the grains should not be present. Based on the described effects on cracking between the different types of concrete in this static fracture-mechanics, differences are also expected under high rates of loading.

Investigations at the Technical University of Dresden observed these differences in the fracture behavior under high rates of loading. For this purpose a specially designed device was developed, which can transfer a short traction force of 70 kN in a few milliseconds to concrete specimens.

Tests carried out show that high-strength concrete also experiences an increase in the tensile strength, but with a substantial smaller factor due to the missing viscose behavior.

Research on the crack surface has shown a higher fragmentation of this area compared to surfaces of the quasi-static tests, so that the real crack surface increases. Due to this fact, the ultimate bearing force increases too, because it is dependant on the ultimate tension stress and the real surface.

1 INTRODUCTION

In the year 2000, an impact machine for the investigation of dynamic material properties of concrete was developed at the institute of concrete structures at the Technical University of Dresden. Details of this device are previously presented in Curbach / Ortlepp [1].

Figure 1 shows the findings of the dynamic behaviour, gained from impact tensile tests. In this overview, the increase of the tensile strength is plotted against the strain rate. In the figure, different results of with different ultimate cube strength in compression of the respective sample are represented.

As can be seen from the graph, the increase of the ultimate tension strength of high-strength concrete is less than that of the plain concrete, due to the brittle behaviour on tensile loading. On plain concrete, additional tensile forces can transmitted as a result of the ductile pullout of grains from the cement paste. But at high-strength concrete no pullout exists. Still, there seems to be a difference between the cracking process of quasi-static and the cracking process of dynamic loading.

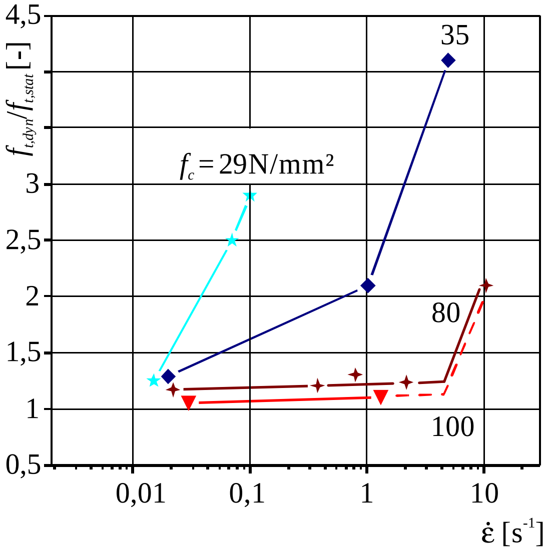

Figure 1: Ultimate tensile strength ratio subjected to strain rate and cube strength

The surface of the fracture area was observed more closely to analyze this difference.

2 INVESTIGATION OF THE CRACK SURFACE

2.1 General remarks

One possibility of evaluating picture data arrays is the description of periodic signals in the frequency range. Periodic signals can be generally represented as Fourier series. The signals are divided into their harmonious components. The Fourier transformed signal accurately contains the same information in the frequency range, as the associated signal in the time range. They only differ in the kind of representation of the information. This permits the view for a function from another point of view, i.e. within the transformed range (frequency range). The signals are analyzed with the FFT-algorithm (Fast Fourier Transformation) from Colley [2].

2.2 Examination of the fracture surface

Two-dimensional arrays, which consist of a number of individual signal components, can only analyzed problematically with the help of an x-y-representation, like a normal two dimensional diagram. Analysis and synthesis of linear signals can be transformed by a temporal dependence into frequency dependence. Also pictures with the local spatial coordinates x and y can be transformed into spatial frequency pictures with the spatial frequencies f_x and f_y. Generally, the transformation from the time range (spatial range) into the frequency range is also called Fourier transformation.

The calculation of the spatial frequency pictures of the fracture surfaces proceeds via the analysis of the altitude profile. For this investigation, a so-called unidimensional FFT is used. Here, the fracture surface is scanned line-by-line. A separate frequency spectrum is generated for each series of measurements for each line. This frequency spectrum is written back to the same line of the data array. The result is a data array, which consists of many parallel frequency spectra. Thus, a line-by-line evaluation of the spatial frequencies along the fracture surface is possible. Figure 2 descriptively shows the arithmetic operation.

The fracture surface of a high-strength concrete essentially consists of broken aggregates and of broken cement paste. Unbroken aggregates are hardly present.

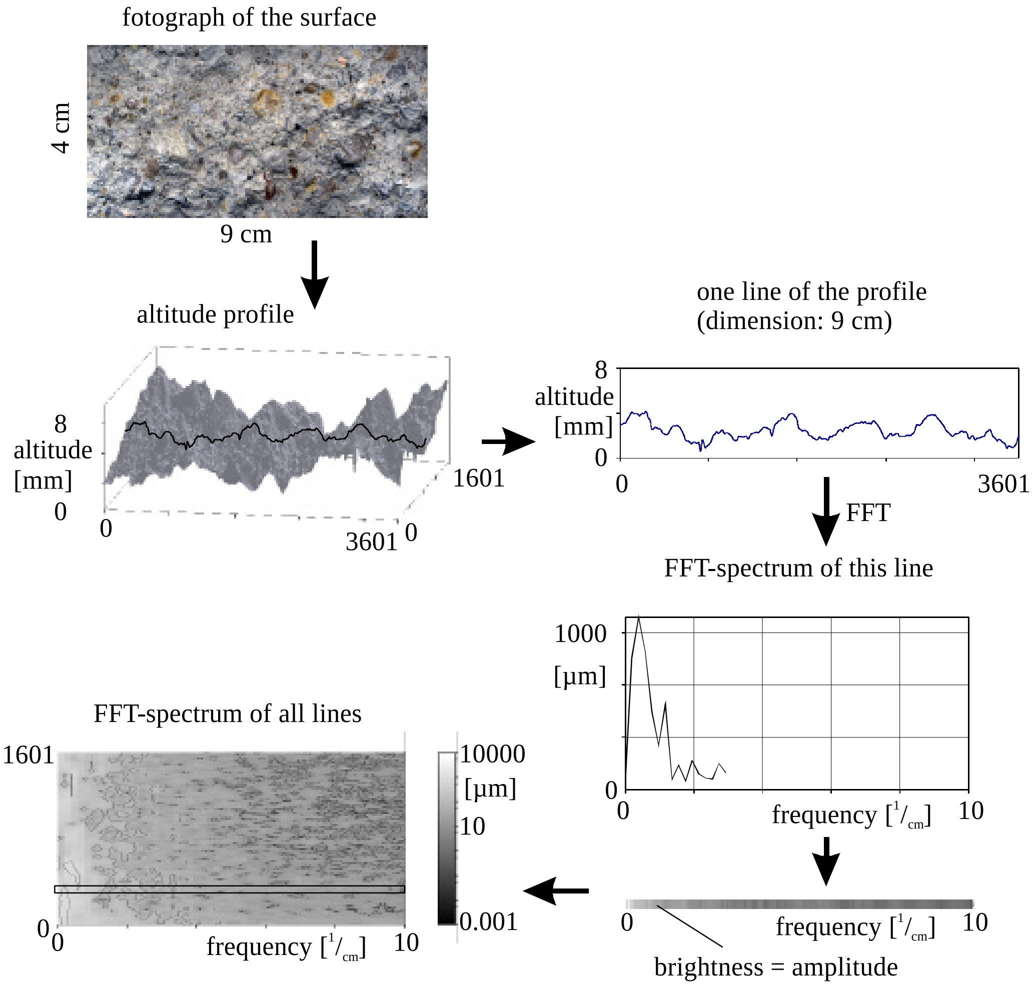

Figure 2: Scheme of determination of spatial frequency spectra

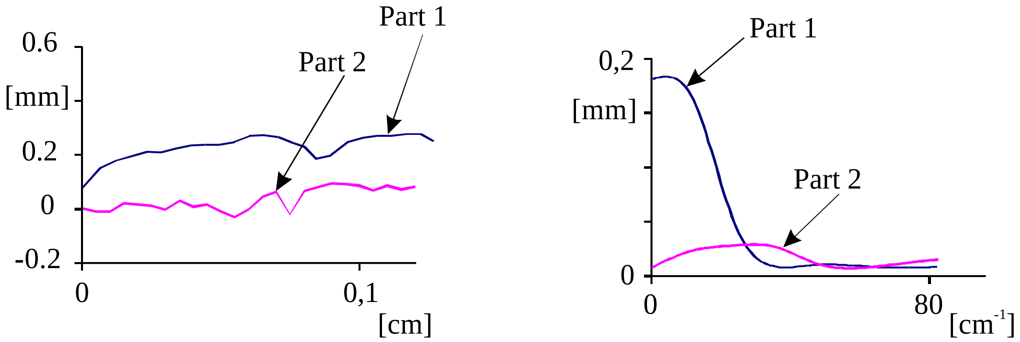

Figure 3: Cuts of surfaces of different load history

Special attention is drawn here, to the general condition of the fracture surface. Two cuts for different parts of the surfaces with different loading histories are represented in Figure 3.

As already seen from the optical impression, a relatively smooth surface produces a larger oscillation period than a rougher surface. This characteristic oscillation appears as a local maximum in the frequency spectrum.

2.3 Results of the spatial frequency spectrum

The tested fracture surfaces have dimensions of 4 cm × 9 cm. These fracture surfaces were scanned at intervals of 25 µm by means of a laser beam. Due to this, the developed surface array has the dimensions of 1601 × 3601 values. Figure 4 shows the examined surface profiles.

Therefore, all lines of the data array have of a length of 3601 measured data values. These individual vectors are subjected to the FFT. Every determined fre-

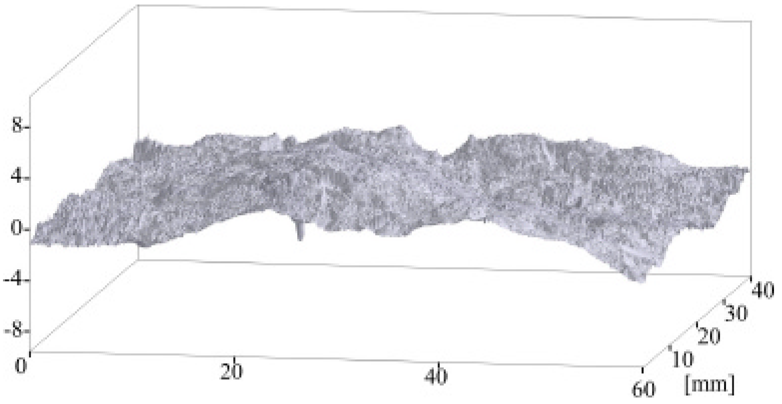

Figure 4a: Typical fracture surfaces of a high loading rate

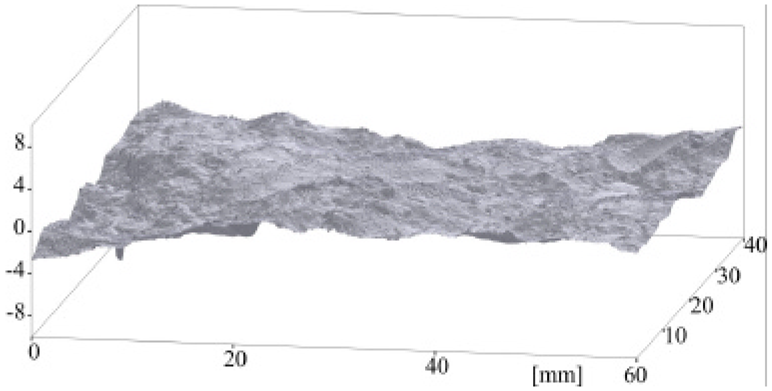

Figure 4b: Typical fracture surfaces of a low loading rate

quency spectrum of the respective vector is written back to the same line of the surface data array.

The surface of the low loading rated concrete seems to be smoother. This impression can be confirmed by calculating spatial frequency spectrum. The study of the fracture surfaces for quasi-static loading and dynamic loading leads to the following spatial frequency spectra (Figure 5 and Figure 6).

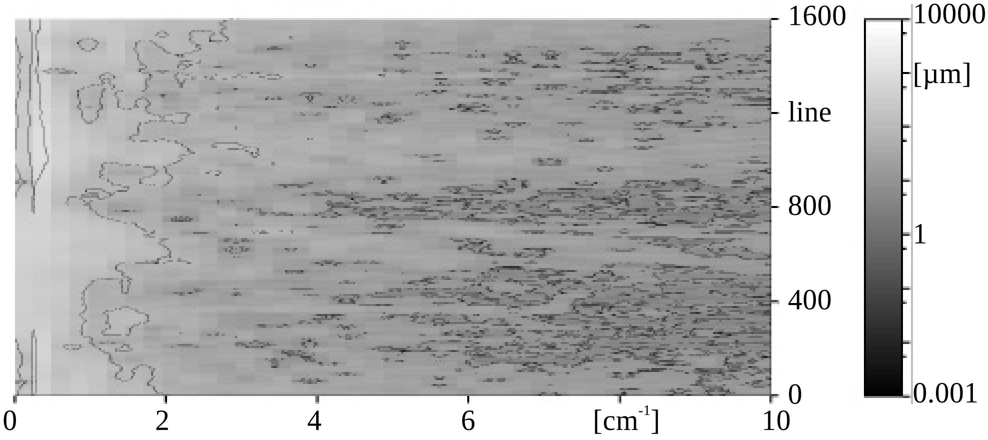

Figure 5: Spatial frequency spectra at quasi-static loading

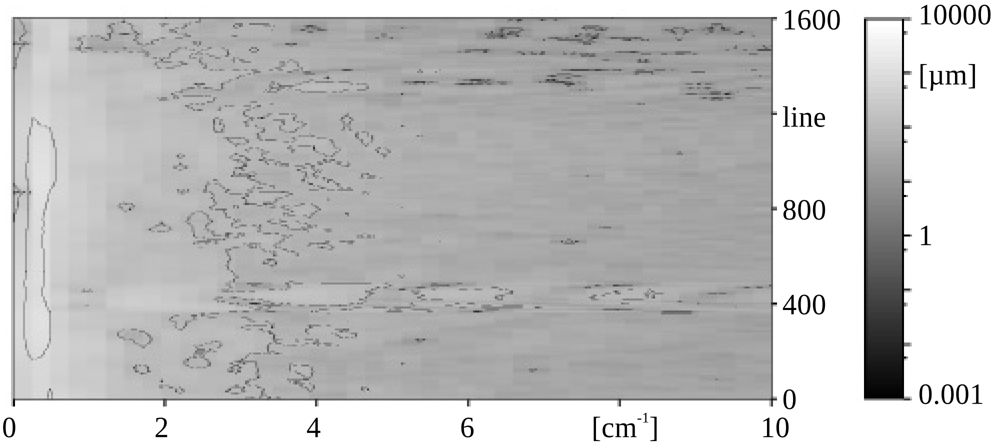

Figure 6: Spatial frequency spectra at dynamic loading

The brighter ranges refer to larger amplitudes of the frequency in each case. Here, the frequency displacement can be clearly recognized in both spectra. At the fracture surface of the quasi-statically loaded specimen, the deep frequencies are dominant. In contrast, the frequency spectrum of the dynamically loaded fracture surface shows higher frequencies, an indication of a rough surface.

3 CONCLUSIONS

Higher spatial frequencies represent an increase of the roughness or fragmentation of the fracture surface. A higher fragmentation leads to an increasing of the total fracture area. In contrast to the smooth surface of slow loaded specimen, the ultimate tensile stress of the concrete material increases too, due to the additional force transmission of the larger area. This effect leads to an increase of the tensile strength at high rates of loading even on high-strength concretes.

4 REFERENCES

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