Fracture Mechanics of Concrete Structures
Proceedings FRAMCOS-3
AEDIFICATIO Publishers, D-79104 Freiburg, Germany

DETECTING FREEZE-THAW DETERIORATION OF CONCRETE BY A FRACTURE MECHANICS METHOD

H. Schorn,
Department of Civil Engineering, University of Technology Dresden,
Dresden, Germany
St. Kopp
Department of Civil Engineering, University of Bochum, Bochum,
Germany

Abstract

As already reported on the first FramCos conference in Breckenridge, Colorado, USA, a very precisely tensile testing method has been developed. Evaluating tensile stress-strain curves measured from unnotched specimen, e. g. a G_F-value according to Hillerborg et al., can be determined.

Nowadays this method has been improved again. Thus G_F as well as the slope of the curve can be evaluated. We get information of occuring microcracks in material structure due to freeze-thaw treatment already in that early state of deterioration where the surface of the specimen is still untouched.

The results of this work may be basic for developing the first freeze thaw-testing method which is physically based on fracture mechanics and does not longer need deteriorated surfaces, crack caused volume increase or other phenomena which do occure only after a relatively great number of freeze-thaw cycles.

Key words: Uniaxial tensile test, bypass loading, microcracking, bending test device, freeze-thaw deterioration, energy of crack formation

1 Introduction

Very precise tension tests on unnotched concrete specimens are a very helpful tool for investigating microcrack mechanisms according to load or even to corrosion damage. Previous work has shown the great advantages of this experimental method in doctor thesises of Budnik (1985), Roßbach (1995b) and Middel (1995a) as well as in contributions to congresses (1992), (1993), (1994). Kopp (1997) has simplified this method to a bending test saving the high level of the precise tension test method.

It has been proved that conventional tests and test evaluation methods according to linear or nonlinear fracture mechanics are not sufficient or helpful. Other types of energy based evaluation methods as proposed by Hillerborg et al. (1976), Bazant et al. (1983) or Cedolin et al. (1987) seemed more helpful. Especially the method of Hillerborg was useful to be modified and developed to a method which Middel has proposed in a doctor thesis (1995a).

Using both, the high developed tension test method - or bending test method, resp. - and the modified test evaluation method, a test for early detection of freeze-thaw deterioration can be developed successfully.

2 Crack mechanisms in material structure of concrete

As principally shown in (1993) existing microcracks in an unloaded concrete body will not propagate due to load. But new microcracks will occur, and then form microcrack accumulations from where a macrocrack then will start. Fig. 1 shows a stress-strain curve of a tensile loaded body. Unloaded and at a low range of loading some undirected microcracks in the material structure may occur according to stresses from different shrinkage of binder and aggregate, section 1 in fig. 1. With increasing load more and more new microcracks occur mainly directed perpendicular to tensile load direction, section 2 in fig. 1. Of high interest is section 3 in fig. 1 which is overlapping the microcrack mechanisms of section 2. In section 3 the directed microcracks are forming microcrack accumulations. The process starts already in the ascending branch of the stress-strain curve, continuous up to the point of strength in the maximum of the curve and is still active in the descending branch. From one of the microcrack accumulation zones a macrocrack starts, section 4 in fig. 1 and propagates over the whole cross section of the body.

In the ascending branch of the curve new microcracks will be formed and will form a first accumulation zone before the peak point of strength in the ascending branch of the curve, point A in fig. 1. In the descending branch of the curve a macrocrack will start from an accumulation zone. The macrocrack will propagate until the whole cross section will be damaged and the load transferring capacity will be diminshed to zero. In section 3 in fig. 1 the crack mechanisms are changing from forming new (micro)cracks to propagation of a single (macro)crack. Thus the determination of points A and B in fig. 1 is of high interest.

3 Test and evaluation methods

Already in (1985) it was found how to determine point A in fig. 1 where microcrack accumulation is starting. Determining point B is more difficult. From experiences of numerical simulation work a rough approximation was given in (1991). A sharp experimental determination has found using tensile tests on concrete principally as follows:

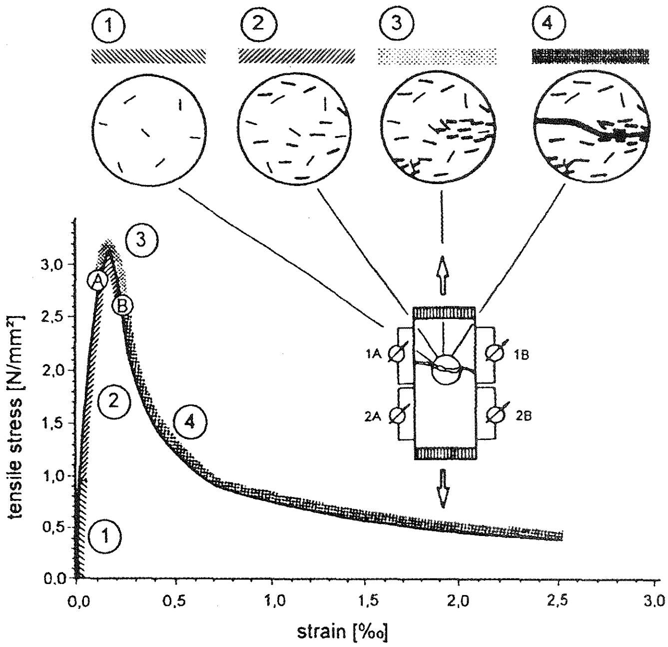

Fig. 1: Crack states at different sections of tensile stress-strain curve (1993)
1 Initial microcracks due to shrinkage
2 Microcrack forming due to loading
3 Microcrack accumulations
4 Macrocrack propagation

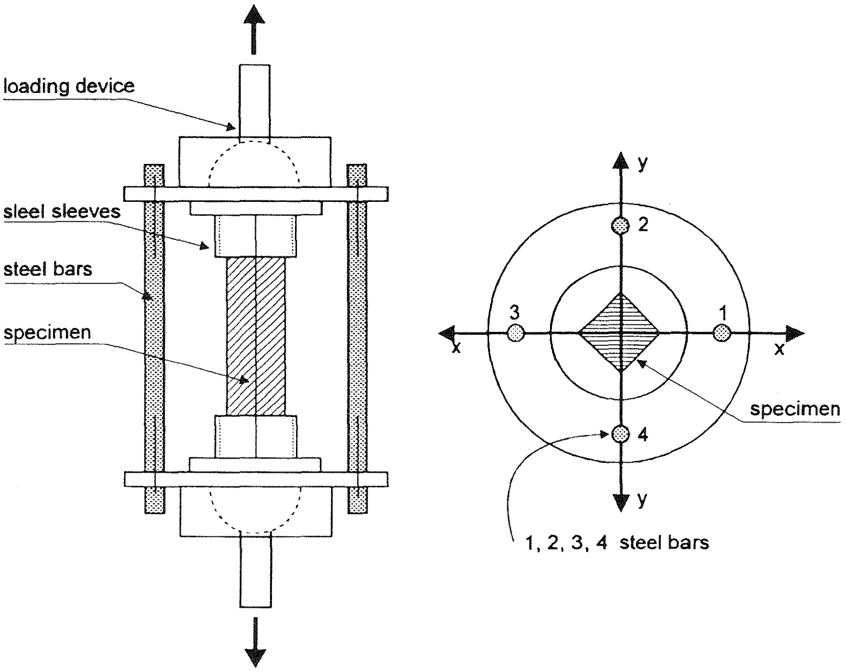

Fig. 2: Tensile test device using 4 bypassing steel bars (1995a)

Fig. 2 shows the test device. The load is transferred as well by the concrete specimen as by 4 bypassing steel bars. Strain measurements allow to plot a stress-strain curve as shown in fig. 1. Evaluating the strain measurements of the 4 steel bars separately, an important additional information can be found. Up to point A in the ascending branch of the curve the load in all steel bars increases similar. But according to the unavoidable inhomgeneity of concrete material structure we can measure a rotation on x- and/or y-axis in fig. 2, right side. Fig. 3 shows rotation over elongation of steel bars 1 and 3 (x-axis) and steel bars 2 and 4 (y-axis). Up to point A (see fig. 1) no alteration happens. Both curves remain parallel. Between point A and point B (see fig. 1) new microcracks occur and form microcrack accumulations. New inhomogeneous zones in the concrete body are the consequence which is measured by alteration of rotations in x and y-axis up to point B in the descending branch of the stress-strain curve. Beneath point B a new balanced position condition can be found due to (macro)crack propagation. More detailed information is given in (1995a).

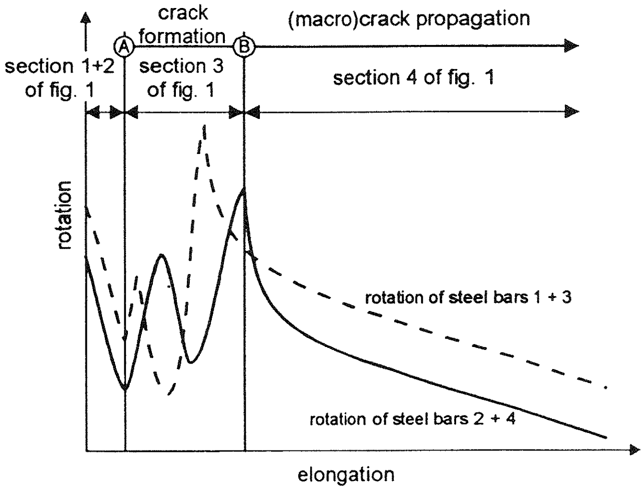

Fig. 3: Measurement results of rotation for x-axis, steel bars 1 + 3, and y-axis, steel bars 2 + 4 according to fig. 2, right side

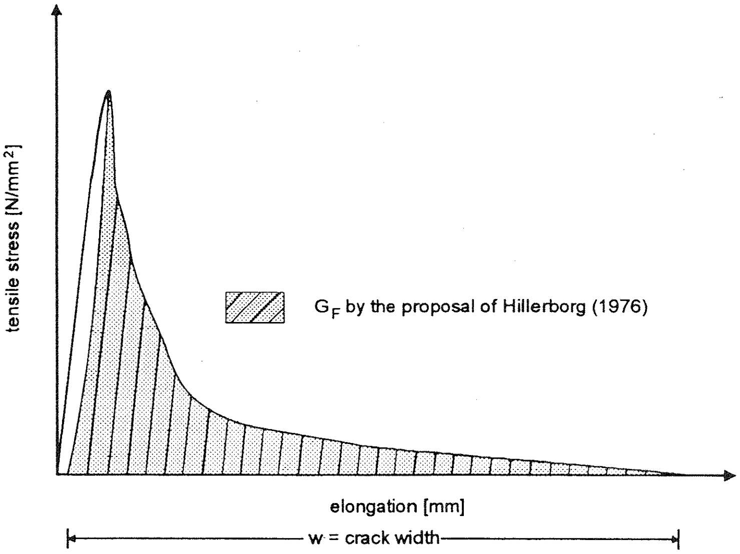

Fig. 4: Evaluation of fracture energy of microcrack forming and macrocrack propagation

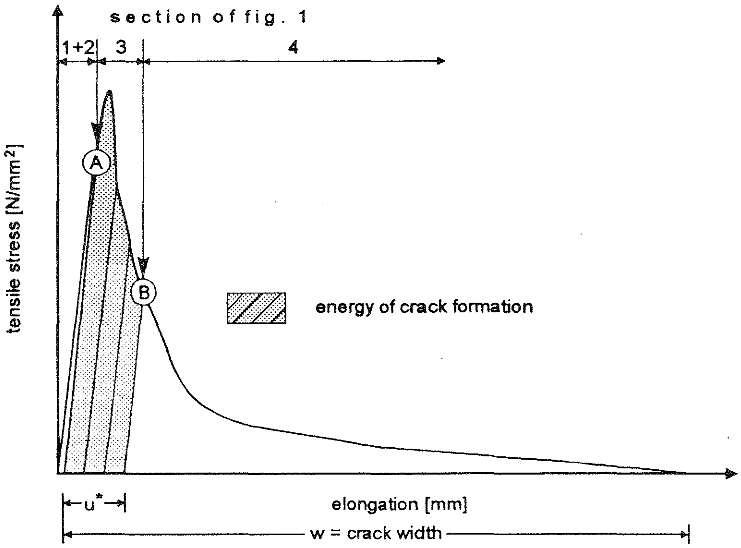

Fig. 5: Evaluation of fracture energy of microcrack forming

Consequently Middel proposes to modify the G_F-determination as given by Hillerborg et al. (1976) (see fig. 4), which includes crack formation energy as well as crack propagation energy. As shown in fig. 5 Middel evaluates only crack formation energy and gets a very sharp indicator even for those crack formation processes in material structure which are caused by corrosion or by freeze-thaw attack.

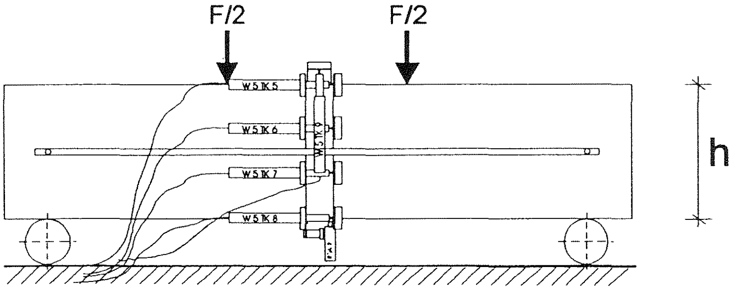

Fig. 6: Bending test device with 4 LVDT's (Kopp 1997)

4 Freeze-thaw crack formation

The experimental method of precise tension tests on unnotched concrete specimens is not easy to carry out. Experienced researchers are needed. Not all material testing laboratories are able to do these tests. Due to this disadvantages the method has to be simplified without losing evidence. Kopp (1997) has developed a bending test as shown in fig.6. Compressive as well as tensile strain is measured by 4 LVDT's. Evaluating bending test results we can use a similar energy criterion to that Middel (1995a) has proposed due to the precise tension tests. Fig. 7 shows point A in the ascending and point B in the descending branch of the stress-strain curve in the analogous manner as already shown in fig. 5 according to tensile test results, Kopp (1998). Point A can be determined exactly in a stress-strain curve according to bending tests if the first value of the addition from tensile and compression strain is not equal to zero. There is a greater tensile strain than compression strain increase caused by the extended microcrack forming above point A in the ascending branch. At point B in fig. 7 there is no more stress tansfer at the bottom side of the specimen; the zero point between tensile and compression stresses in the beam then is approximately situated in h/3 below the upper side (see fig. 6).

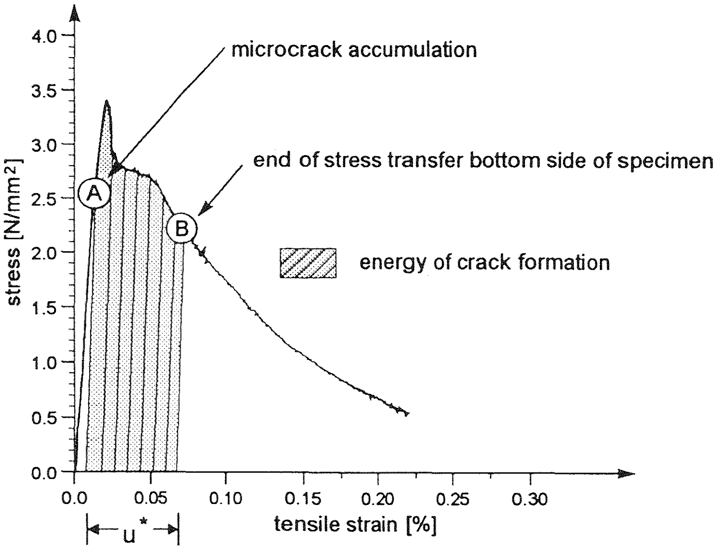

Fig. 7: Evaluation of fracture energy of microcrack forming from the bending test (see fig. 6) (Kopp 1998)

Now the method is simple enough for deterioration tests. If a freeze-thaw damage will occur after a lot of freeze-thaw cycles, there must be an internal damage processes in material structure by each cycle. If a test method is efficient enough it must be possible to prove an effect even after one freeze-thaw cycle only. That has been done in a frost chamber. First the energy of crack formation has been measured for different concrete ages as shown in fig. 8. Curve A, is obtained with the evaluation method as explained in fig. 7. These specimens were not treated by frost or frost-thaw cycles. Curve A in fig. 8 is rising due to the hardening process of concrete. The results of energy formation measurements after one freeze-thaw cycle only are compared to this curve. 38 days old concrete shows a significant decrease of fracture energy after one cycle down to -5 °C (+ 23 °F). The difference to curve A is that energy needed for frost-thaw caused microcrack forming in material structure. The same effect can be shown on 45 days old specimens after one cycle down to -20 °C (-4 °F). As to be expected the lost energy due to freeze-thaw structure damaging is relatively greater. In fig. 8 the evaluated energy has been related to that strain value which is determined by the crack forming energy between points A and B (see u* in figures 5 and 7). Middel (1995a) has shown that this method is very useful for energy based characterization of alterations in material structures.

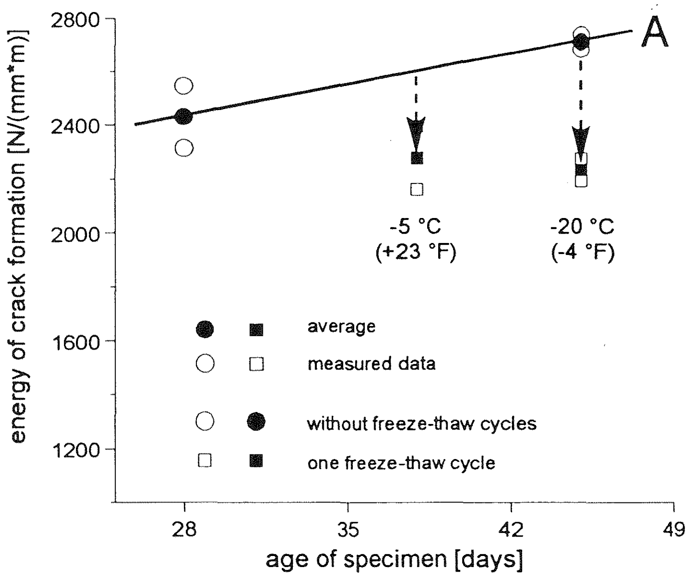

Fig. 8: Reduction of measured fracture energy due to energy of freeze-thaw caused microcrack forming in concrete structure

5 Conclusions

- Very precise tension test on unnotched concrete specimens allows to determine fracture energy, but evaluation of fracture energy as G_F-value according to the proposal of Hillerborg et al. (1976) does not distinguish between energy for forming microcracks and energy for propagating of a macrocrack. An advanced proposal of Middel (1995a) can be used successfully.
- Even after one freeze-thaw cycle only an alteration of material structure can be proved according to internal damaging processes. A simplified particular method of high evidence using bending test instead of tension test has been considered as sufficient.
- In future fracture energy based test methods may replace the freeze-thaw methods of today which require crack caused volume increase or even visible damages.

6 References

Bazant, Z. P.; Oh, B. H. (1983) Crack band theory for fracture of concrete. **Materials and Structures**, 93, 155-177.

Budnik, J. (1985) Bruch- und Verformungsverhalten harzmodifizierter und faserverstärkter Betone bei einachsiger Zugbeanspruchung. Thesis. University of Bochum.

Cedolin, L.; Dei Poli, S.; Iori, I. (1987) Tensile Behavior of Concrete. **Journal of the Engineering Mechanics**, 113 (3), 431-449.

Hillerborg, A.; Modeer, M.; Petersson, P. E. (1976) Analysis fo Crack Formation and Crack Growth in Concrete by Means of Fracture Mechanics and Finite Elements. **Cement and Concrete Research.** 6, 773-782.

Kopp, St. (1997) Experimentelle Nachweise von Gefügeänderungen im Beton. 34. Forschungskolloquium des Deutschen Auschuß für Stahlbeton. 187-196.

Kopp, St. (1998) Beurteilung von Gefügeänderungen infolge Rißbildung im Beton. Vorträge der 30. Sitzung des Arbeitskreises Bruchvorgänge. Deutscher Verband für Materialprüfung e. V., Dresden. 449-458.