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Tensile Strength Concrete: Prodigal Son or Primary Source?

Résistance à la traction du béton: qu'en est-il?

Die Zugfestigkeit des Betons: verlorener Sohn oder Urquelle?

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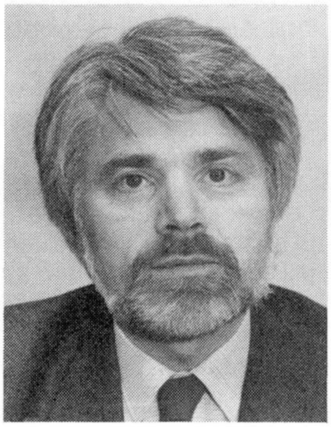

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SUMMARY

Based on results of fracture mechanics and numerical modelling of concrete, the important role of the tensile strength as material property is discussed. The contribution shows that a) contrary to popular opinion high-strength concretes have a relatively high compressive strength compared to their tensile strength, b) the conditions in a structural concrete structure can be better characterized with a tension rather than a compression field, c) tensile strength of concrete must become an integral part of any physical model, d) tensile tests and not compressive tests should be applied in Quality Assurance.

RÉSUMÉ

Tout en se référant aux résultats donnés par la mécanique de la rupture et à la simulation numérique du béton, on discute du rôle primondial de la résistance à la traction du béton par rapport à la résistance en compression. Ce rapport met en valeur quatre aspects: a) Contrairement à ce que l'on pourrait penser, dans un béton à haute résistance, la forte résistance en compression ne va pas de pair avec la résistance en traction mobilisable. b) Les conditions régnant dans une structure en béton armé peuvent mieux être caractérisées par un champ de tractions que par un champ de compressions. c) Le résistance à la traction du béton doit devenir partie intégrante de tout modèle physique. d) Dans tout contôle de qualité, on devrait donner la priorité au test de résistance à la traction par rapport au test de résistance en compression.

ZUSAMMENFASSUNG

Bezugnehmend auf Ergebnisse, die bei Anwendung der Bruchmechanik und numerischen Modellierung zur Erforschung des Betons entstanden, wird die zentrale Bedeutung der Betonfestigkeit hervorgehoben. Der Beitrag zeigt, dass a) im Gegensatz zur allgemeinen Auffassung, die hochfesten Betone eine höhere Druckfestigkeit in bezug auf ihre Zugfestigkeit aufweisen, b) der Beanspruchungszustand eines Tragwerks aus konstruktivem Beton kann besser mit einem Zugfeld als mit einem Druckfeld beschrieben werden, c) die Zugfestigkeit muss als ein wichtiger Bestandteil aller physikalisch integeren Modelle betrachtet werden, d) die Qualitätskontrolle sollte statt die Druckfestigkeit, die Zugfestigkeit des Betons prüfen.

1. INTRODUCTION

Concrete is a inhomogeneous building material. It has a considerable and reliable compressive strength and a relative law tensile strength which can be even exhausted locally under unfortunate conditions, e.g. due to the hydration heat of cement or to its plastic shrinkage. It is quite obvious that the concrete tensile strength was always reprehended as the most unreliable concrete property.

As the compressive strength of the conventional test specimens (200 mm cubes or 150/300 mm cylinders) was rather insensitive to most of the aforementioned influences and it was convenient to be measured, it became accepted by the material science, the design office and the construction site as the fundamental mechanical property of concrete.

Several other properties were deduced empirically by the help of best–fit formulas using the compressive strength as basic variable.

The mean and fractile values of the different tensile strengths too became a function of compressive strength [1]. The degressive character (e. g. the fractional exponent) of this function reflects that high strength concretes have a relative lower tensile strength compared to low strength concretes. Obviously high strength concretes has been always treated as less perfect concretes.

According to a sad terminology, students learn to neglect the concrete tensile strength at dimensioning any s. c. member. Even the CEB–FIP Model Code [2] uses this verb, in EC 2 [3] the tensile strength will be ignored. (As a matter of fact, this applies to dimension the flexural reinforcement only.) In dimensioning of watertight or prestressed concrete members the tensile strength will be relied on with a shy consciousness of guilt.

Even quite recent engineering models for s. c. try to circumscribe those phenomena (e. g. bond) where the tensile strength is the main influencing factor. Thus the modeling of a slab without shear reinforcement became a quite unsolvable problem.

All these problems could be easily removed if we realize that the tensile strength is a more fundamental mechanical property of concrete as the compressive strength is.

The introduction of fracture mechanics and numerical modeling to describe the fundamental behaviour of concrete provides the chance to understand it and to rectify the hierarchy between tensile and compressive strength.

This paper intends to contribute to the acceptance of the tensile strength as a more fundamental concrete property.

2. COMPRESSIVE STRENGTH VS. TENSILE STRENGTH OR VICE VERSA

At the early seventies texture–oriented material models were developed to investigate the mechanism of the internal load bearing system of the two–phase composite material concrete [4], [5]. These models yielded qualitative and partly quantitative predictions on the load bearing and failure mechanisms as function of the rigidity– and strength–relationships between the cement matrix and aggregates. It was concluded that the characteristics of the interface between matrix and aggregate are the primary source of the mechanical properties. Depending on the differences in the rigidities of matrix and aggregates resp. the load trajectories are forced to local deviations in their course shich cause tensile stresses in the matrix and on the interface. These result in microcracks and inelastic response of the concrete. The microcracks were detected during compression tests [6].

During development of their model for "numerical concrete" Wittmann et al. [7] too realized the important influence of the interface on behaviour of concrete, the "mesolevel model" has been introduced.

The texture–oriented and the numerical models resp. showed that both, the compressive and tensile strength have the same origin: the adhesion of the matrix to the aggregates. Under tensile conditions the interface is stressed directly, under compressive conditions indirectly. In this latter case some internal redistribution in the load bearing system is possible, this is the source of the toughness of concrete under compression.

As methods of fracture mechanics had been applied to investigate concrete, it was not by chance that tensile and flexural tests were applied to determine the fracture energy, e. g. the fundamental characteristic of the material concrete, and not any compression test.

Thus we may hope that the traditional empirical way, how to deduce the tensile strength from the compressive strength will be converted to a physically right relationship: the compressive strength will be deduced from the tensile strength and the fractional exponent will disappear as well.

This would become an important step towards more reliance upon concrete tensile strength.

3. COMMENTS ON THE RELATIVE LOW TENSILE STRENGTH OF HIGH STRENGTH CONCRETES

The most important differences between the texture of a high strength concrete and a low strength concrete resp. are the higher stiffness and strength of the cement matrix and its higher adhesive strength to the aggregates in high strength concretes. Due to the quite similar stiffnesses of matrix and aggregate in high strength concretes the inner trajectories under compressive loading conditions are not forced to stronger local deviations, hence the induced stresses along the interface remain relative small. This results in a higher compressive strength compared to the given adhesive strength of the interface.

Thus a high strength concrete must not be reprehended any more for its relative low tensile strength but should be praised for its relative high compressive strength.

This would be an other step to recognition of the tensile strength.

4. COMPRESSION FIELD OR TENSION FIELD?

Soil has, similar to concrete, a low tensile strength compared to its compressive strength. The experts of soil mechanics continued to check form, position and load bearing capacity of sliding surfaces in soil structures even after introduction of the theory of plasticity.

Similar to soil structures, the condition of s. c. members can be better described with a tension field than with a compression field, unless the member will become over–reinforced,

The condition in different parts of a s. c. member can be characterized in relation to the probability of exceeding a certain fractile value of the tensile strength (f_{ctk}) in serviceability and ultimate limit states resp. This probability determines the necessary steps of dimensioning and the type of reinforcement to be applied:

- regions which probably remain free of cracks in ULS get minimum reinforcement
- regions where f_{ctk} will be exceeded in ULS, but probably not in SLS, must be reinforced without fulfilling the requirements in SLS. (As upto the ULS the tensile strength has been already exhausted, it can not be taken into account – instead of to be neglected or ignored – at fulfilling of equilibrium conditions. The usage of the verbs "neglect" or "ignore" is not correct.)
- regions where f_{ctk} has been exceeded already in SLS, the requirements both in ULS and SLS must be fulfilled as well.

This classification can not be achieved with any classes of effective compressive strengths of any compression field theory. Here once more the superiority of the tensile strength over compressive strength is highlighted.

5. BIAXIAL STRENGTH OF COMPRESSIVE STRUTS

Theory, experiments and practice prove that the concrete can be loaded bi– and triaxially, it has strengths in all directions [8].

The rapid decrease of the compressive strength under influence of transversal tensile stresses should not merely be considered at reduction of the axial strength of some compression elements in engineering models, but even the transversal tensile load bearing capacity of those compression elements which are not stressed upto the uniaxial prism strength should be realized as well.

According to the assumed strain distribution in the compression zone at ULS in flexure, only the most exterior concrete fiber reaches the compressive failure strain, all others have $\epsilon_c < \epsilon_{cu}$. This means that the load bearing capacity of any compression zone has a reliable transversal component as well, which is, as a matter of fact, the main part of the V_c term [9].

In ULS each fiber of the compression zone in a s. c. member with bending and shear, will fulfil the failure criterion simultaneously, the whole compression zone will fail at the same time. This was experienced and interpreted as the brittle character of the compression zone's failure under shear loading. The transversal stresses in the compression zone can be decreased with a transversal (shear) reinforcement but they can not be eliminated. Compatibility conditions will determine the effective ratio between V_c and V_s.

Accepting the biaxial strength of concrete some interpretation problems of recent engineering models [10], e. g.

- the shear strength of shear–unreinforced slabs
- the increase of the shear strength due to prestressing

would vanish immediately.

6. QUALITY ASSURANCE WITH TENSILE TESTS ON SITE

Performance and durability aspects have revealed the importance of concrete curing. The tensile strength is more sensitive to mistakes during curing as the compressive strength is.

In previous clauses the central part of tensile strength as concrete property has been discussed.

All these circumstances can leed to the conclusion that the quality control of s. c. structures should be performed with tension tests on the structure on site and not with compression tests on cubes or cylinders in the laboratory.

7. SOME COMMENTS ON THE INVITED LECTURES

7.1 Comments on the Test Setups

It is beyond any dispute that the uniaxial tension test is the most direct way to determine a strain–softening diagram. As it is difficult to carry out uniaxial tension tests on concrete under strain–controlled conditions, simpler test setups have been looked for and applied.

In order to achieve simply interpretable test results, test specimens with predetermined failure surfaces, e. g. notched beams in three point bending tests have been proposed as RILEM Recommandation [11]. It must be kept in mind that the predetermined failure surfaces do not yield that fractile value of G_F, which will govern the failure characteristics of a given test specimen, as it will fail along its "weakest" surface, with the lowest G_F.

The specimen's form and the boundary conditions of that test, shich should yield more understanding about the fundamental properties of concrete need and must not be the simplest one, otherwise we shall have the same situation as with the compressive strength: we shall order and evaluate using an argument only for the reason that it is simple to be determined. It must be cleared up, which of the properties belong to the test setup, the specimen's behaviour and the material behaviour resp. as proposed in [13].

7.2 Comments on the Properties of the Fracture Energy

Fracture energy must be unique and independent of specimen type, size and shape. Size effect laws are felt to be created using the nominal stress

$$\sigma_N = P / (b \cdot d)$$

at evaluation of test results. These laws could be eliminated if the effective depth d_{ef} would be applied at evaluation of test results. The effective depth is that part of the specimen's depth, which is activated when the fictitious crack has first even came up to its maximum width (w_2). It is felt, that even the apparent dependence of the specific fracture energy with increasing ligament length could be eliminated using d_{ef}.

If it is true, that fracture energy is a material property, which has no direct connection with other material properties, such as the compressive strength [12], then we should look for more fundamental material properties, as after all, concrete is a quite simple composite, consisting of a porous matrix, aggregates and an interface between them. Nevertheless, as the influencing factors are the same as for the other mechanical properties [13], we will soon have a quite complete and coherent understanding for these properties and their relations.

REFERENCES

1. RÜSCH H., Die Ableitung der charakteristischen Werte der Betonzugfestigkeit. Beton 1955
2. CEB–FIP Model Code for concrete structures, 1978
3. Eurocode No. 2 Design of Concrete Structures. Final Draft 1989
4. WISCHERS G., LUSCHE M., Einfluß der inneren Spannungsverteilung auf das Tragverhalten von druckbeanspruchtem Normal– und Leichtbeton. Beton 1972
5. MODEER M., A Fracture Mechanics Approach to Failure of Concrete Material. Lund 1979
6. RÜSCH H., Physikalische Fragen der Betonprüfung. Zement–Kalk–Gips. 1959 Heft 1
7. WITTMANN F.H., ROELFSTRA P.E., KAMP C.L., Drying of Concrete – An Application of the 3L–Approach. Nuclear Engineering and Design. 1987
8. KUPFER H., Das Verhalten des Betons unter mehrachsiger Kurzzeitbelastung unter besonderer Berücksichtigung der zweiachsigen Beanspruchung. DAfStb. Heft 229, 1973
9. WALTHER R., Über die Berechnung der Schubtragfähigkeit...Beton– und Stahlb. 1962
10. MACGREGOR J.G., Dimensioning and Detailing. Invited Lecture Sub–theme 2.4
11. RILEM, Determination of the Fracture Energy of Mortar and Concrete by Means of Three–Point Bend Tests on Notched Beams. Materials and Structures 1985
12. HILLERBORG A., Reliance upon Concrete Tensile Strength. Invited Lecture 2.5
13. KÖNIG G., DUDA H., Basic Concept for Using Concrete Tensile Strength. Invited Lecture Sub–theme 2.5

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