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Bending Tensile Strength of Steel Fibre Concrete under High Thermal Loads

Résistance à la traction-flexion de béton de fibres sous sollicitation thermique élevée

Biegezugfestigkeit von thermisch hochbeanspruchtem Stahlfaserbeton

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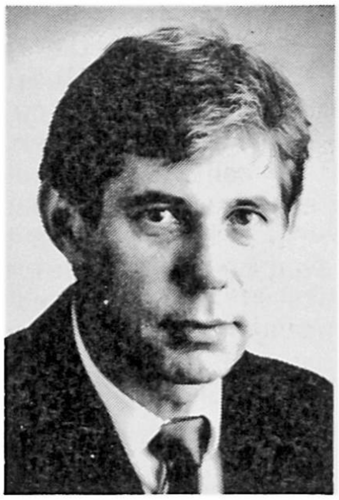

SUMMARY
The use of steel fibre concrete offers considerable advantages with elements and constructions which are exposed to high thermal loads during service or catastrophes (e.g. energy technology, shelters, fires in buildings, LNG-tanks during leakages etc.). To obtain the relevant material data for the design of such elements bending tensile tests have been conducted. Then investigations were mainly concentrated on high temperatures up to 800°C. The low temperature region down to –196°C was investigated to elucidate the fundamental effects of steel fibre reinforcement in microstructurally damaged concrete.

RÉSUMÉ
L'utilisation de béton de fibres d'acier présente des avantages pour les éléments de construction et les bâtiments soumis à des sollicitations thermiques élevées, soit en permanence lors de l'utilisation, soit en cas de catastrophe (p.ex. en technique de l'énergie, abris, coffres-forts, éléments de construction lors d'un incendie, réservoirs à gaz naturel liquéfié lors de fuite). Pour obtenir les données nécessaires sur les matériaux, des essais de traction-flexion ont été faits. Les recherches ont surtout porté pour des températures jusqu'à +800°C. Les basses températures allant jusqu'à –196°C ont aussi été incluses pour mettre en évidence l'influence des fibres d'acier dans un béton à microstructure détériorée.

ZUSAMMENFASSUNG
Die Anwendung von Stahlfaserbeton bietet erhebliche Vorteile bei Bauteilen und Bauwerken, die hohen thermischen Belastungen – entweder dauernd im Betrieb oder in Katastrophenfällen – ausgesetzt sind (z.B. in der Energietechnik, Schutzräume, Tresore, Bauteile bei Schadensfeuern, LNG-Tanks bei Leckagen). Um die für die Bemessung solcher Bauteile notwendigen Materialdaten zu gewinnen, wurden Biegezuguntersuchungen durchgeführt. Hauptsächlich wurde der Bereich bis +800°C erforscht. Die tiefen Temperaturen bis –196°C wurden mit einbezogen, um die grundsätzliche Wirkung von Stahlfasern in mikrostrukturgeschädigtem Beton zu erhellen.

1. INTRODUCTION

Since a number of years the effect of steel fibre reinforcement on the strength and deformation properties of concrete has been quite extensively studied. The results have shown that the incorporation of steel fibres in the relatively brittle concrete or mortar matrix improves the tensile strength properties and ductility of the unreinforced matrices. Because of these particular properties steel fibre reinforced concrete has already got a wide spread application in practice, although, it is a rather expensive material and requires more care in mix designing and concreting.

The results of various studies conducted at the Institute für Baustoffe, Massivbau and Brandschutz /1, 2, 3/ led to the conclusion that steel fibre reinforced concrete also indicates at high as well as at low temperatures, respectively after low temperature cycling a considerable higher ductility and an improved post maximum load behaviour than plain concrete. Obviously the response of constructions and elements exposed to extreme thermal loads under certain service conditions as well as during accidents (like fires in buildings or leakages in LNG-tanks) could be markedly improved by using steel fibre concrete. For instance, slender normal concrete elements like prestressed double-T-girders or beams with thin webbs are, in general, endangered by destructive spalling during a fire attack. On the other hand, composite elements possibly could be manufactured more economically with steel fibre concrete instead of stirrups and longitudinal reinforcement.

The objectives of the research program reported here /4/ were to study the mechanical behaviour, especially bending tensile properties, because they are decisive for ductility and crack formation. The main emphasis was laid on the experimental investigation of the high temperature region up to 800°C. Low temperature investigations down to -196°C were involved, too. It was anticipated that the results of such investigations gain the general understanding of the specific effect of steel fibre reinforcement in microstructurally deteriorated concrete.

2. EXPERIMENTAL

The test programme contained besides the testing temperature and loading conditions the following variables:

- concrete composition (mineralogical type of aggregates (gravel, limestone, diabase), cement content, type of binder (Portland cement, Portland cement + micro silica), W/C-ratio),
- steel fibre content, type of fibres (cut wires (WIREX); Ø = 0,4 mm, ℓ = 25 and 40 mm, resp. crimped cut wires (DRAMIX) ; Ø 0,5 mm, ℓ ≈ 30 mm, machined fibres (HAREX, made of massive steel blocks by milling, with sickle-shaped cross-section)).

The test specimens were small concrete beams (64 mm x 72 mm x 280 mm) sawed out of small concrete slabs, which were stored after concreting for at least 28 days under water. After cutting, the small beams were again stored under water until testing. The basis mix proportions and some concrete data of the various batches are given in Tab. 1.

The test equipment is shown in Fig. 1. The specimen is simply supported. The load is applied by a steel frame which is connected with a steel rod and via a load-cell with a servohydraulic jack. The bending movements are transferred by two fused silica rods through the hot oven and measured by the aid of a magnetic transducer as the difference movement of both the silica rods. The obtained electrical signal is used for controlling the displacement of the hydraulic piston during the bending tensile test. The test procedure is shon in Fig. 2.

basis concrete mix	SF-Q	SF-D	Ko	Do	Quo	Qm0,55	Qm0,65	Mo
cement content [kg/m³]	340	340	340	340	340	340	340	500
silica fume [kg/m³]	60	60	-	-	-	-	-	-
aggregate content [kg/m³]	1824	1854	1884	1854	1847	1847	1847	1500
sand (crushed stone) 0/2 mm	-	35 %	20 %	30 %	-	-	-	-
crushed stone 2/8 mm	-	-	40 %	-	-	-	-	-
crushed stone 8/11 mm	-	25 %	15 %	30 %	-	-	-	-
crushed stone 11/16 mm	-	40 %	25 %	40 %	-	-	-	-
sand 0/2 mm	34 %	-	-	-	34 %	34 %	34 %	69 %
gravel 2/8 mm	26 %	-	-	-	26 %	26 %	26 %	31 %
gravel 8/16 mm	40 %	-	-	-	40 %	40 %	40 %	-
water [kg/m³]	191	200	153	153	165	221	221	250
w/c	0,57	0,59	0,45	0,45	0,485	0,55	0,65	0,5
plasticizer *)	2 %	3 %	1 %	1,5%	1 %	2 %	1 %	1 %
density [kg/dm³] **)	2,35	2,48	2,47	2,48	2,40	2,45	2,43	2,31
cube strength [N/mm²]								
28 d	51	54	51	52	54	54	42	55
when tested	59	59	53	59	65	59	46	64

*) related to cement weight; **) fresh concrete

Table 1 Mix proportions and data of the concrete basis mixtures

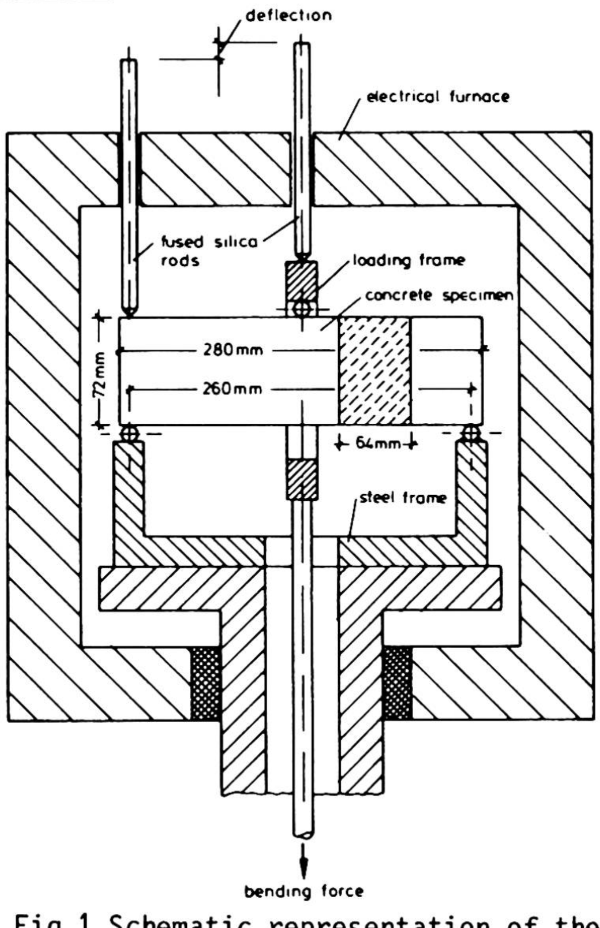

Fig.1 Schematic representation of the test equipment

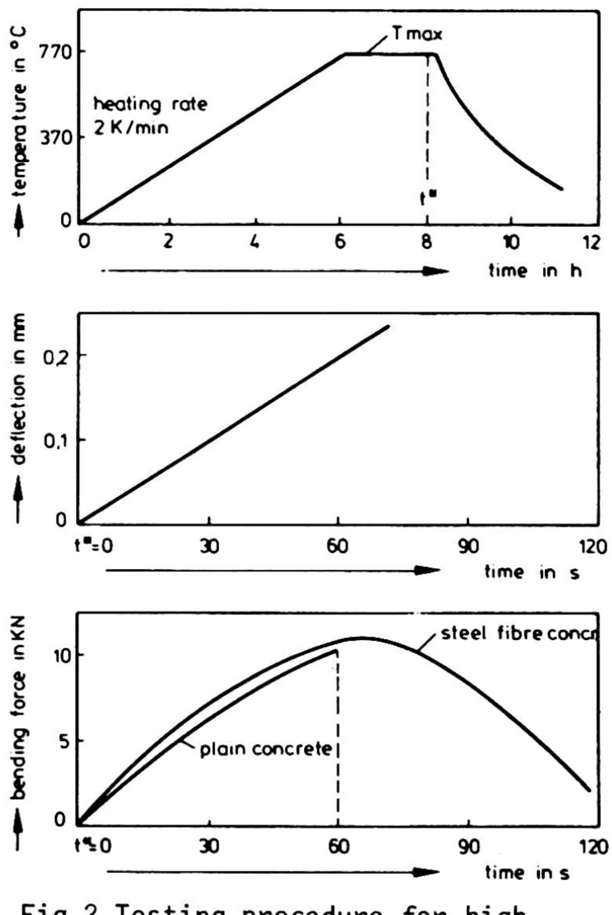

Fig.2 Testing procedure for high temperature investigations

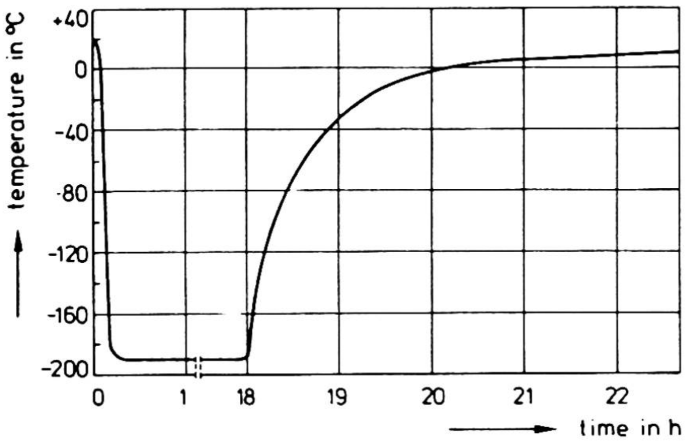

Fig.3 Temperature exposure of "low-temperature-specimens"

The specimens are heated in an electrical oven with a heating rate of 2 K/min to the desired maximum temperature (T_{max}). Then this temperature is kept constant for nearly 2 hours. At the time t* the specimens are loaded with a constant deflection rate of about 0.2 mm/min. Simultaneously the resulting load response is measured. The "low-temperature-specimens" were rapidly cooled down to -196°C by spraying liquid nitrogen into the sample container (Dewar vessel), held for 18 h at -196°C and subsequently slowly warmed up to room temperature (Fig.3), tested in the same way like the 20°C-reference specimens.

3. RESULTS AND DISCUSSION

From the deflection-load response measurements bending force-deflection relationships are obtained as shown in Figs.4 and 5 for Portland cement concrete made with siliceous aggregates tested at high temperature and after low temperature cycling. The y-axis indicates the measured bending forces; the x-axis the deflection in mm, noteworthy, after the onset of matrix cracking the crack mouth opening is nearly half of the measured deflection. The dotted lines in Fig.4 belong to the plain concrete and the full lines represent the response of steel fibre concrete. In this case the fibre content was 3-weight-% of smooth cylindrical fibres with a diameter of 0.4 mm and a length of 25 mm. With other mixtures comparable deflection-bending force characteristics have been obtained. The maximum bending forces - in terms of "bending tensile strength" β_{ts} (defined by the equation $\beta_{ts} = 1.5 \cdot F \cdot l/b \cdot h^2$, F = maximum bending force, l,b,h = length, width and height of the specimens) - of the various mixtures are compiled in Figs.6-9.

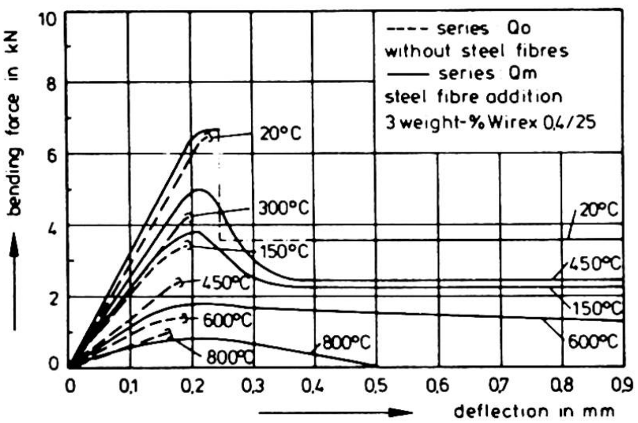

Fig.4 Bending force-deflection relationships of steel fibre reinforced gravel concrete at high temperature

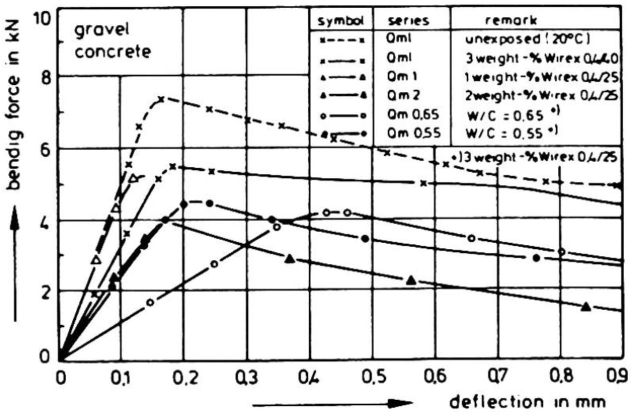

Fig.5 Bending force-deflection relationships of various steel fibre reinforced gravel concretes after low temperature cycling

In the initial parts of the curves obtained at ambient temperature (20°C) hardly any difference between plain and fibre concrete occurs. Both curves run nearly linear up to deflections of about 0.2 mm, then follows a plateau indicating the onset of cracking. A further small increase of the deflection leads to collapse of the plain concrete due to unstable crack propagation.

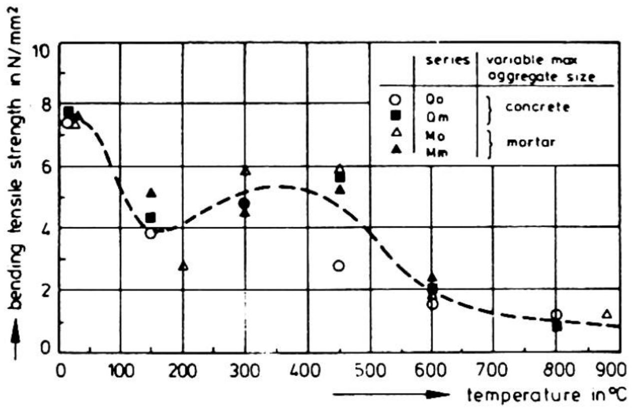

Fig.6 Effect of aggregate size on the bending tensile strength of steel fibre concrete

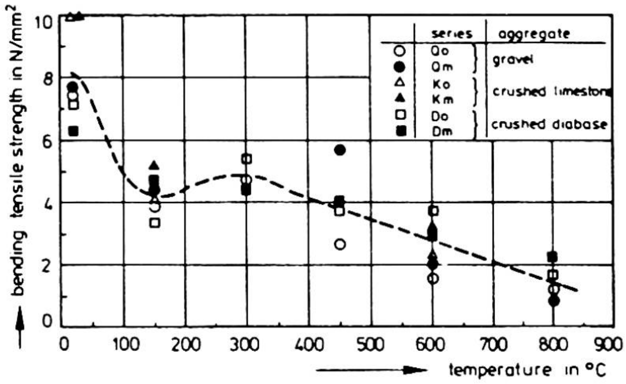

Fig.7 Effect of mineralogical type of aggregate on the bending tensile strength of steel fibre concrete

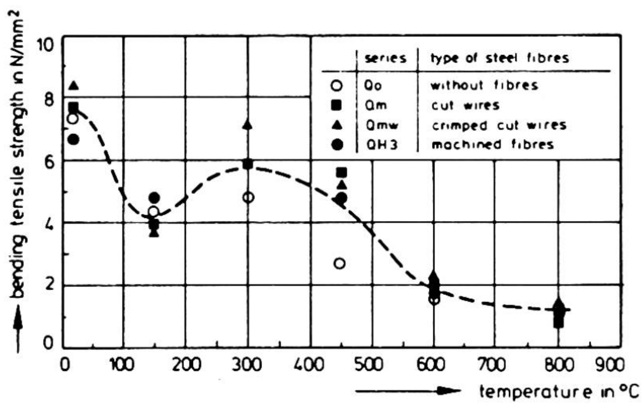

Fig.8 Effect of type of steel fibres on the bending tensile strength of concrete

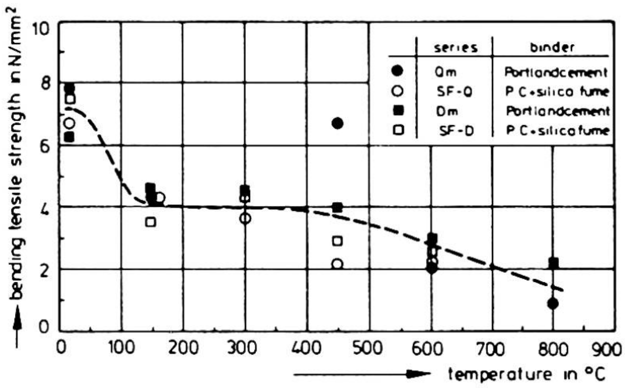

Fig.9 Effect of binder on the bending tensile strength of steel fibre concrete

The steel fibre specimens show a slightly more extended plateau. However, with a deflection of nearly 0.25 mm unstable matrix cracking occurs. This causes simultaneously debonding of fibres and their activation to bridge the gross crack and to transfer tensile loads by frictional forces. The related unstable transition (onset of matrix cracking → continuously cracked matrix) runs too rapidly to be reliably controlled and recorded by the testing equipment, therefore the transient response is indicated by the dashed line in Fig.4.

After deflections of nearly 0.35 mm the deflection-load response is again stable and the load - now significantly lower compared to the maximum level - hardly decreases in course of a further increase of the deflection up to 1 mm.

In the temperature region from 150°C to 450°C the peak stresses of both the plain and the steel fibre concrete are already significantly reduced, although, the peaks are shifted only to a small extent towards lower deflections. As expected, the plain concrete specimens show the same behaviour as the 20°C-specimens. They collapse after the onset of gross cracking. A very similar behaviour is observed after low-temperature-cycling.

The steel fibre specimens indicate a quite different post-maximum-load behaviour than the respective 20 °C-specimens: After exceeding the maximum stress, with increasing deflection the load is decreasing in a stable manner to a certain lower level. This lower and more stable crack propagation originates from the more ductile behaviour of the heated concrete. Since the heated concrete contains a great number of critical cracks, satellite and multiple cracking occurs. This enables a stepwise, respectively continuous activation of steel fibres to bridge the gross crack.

That means both the matrix and the fibres are transferring the tensile stress during the transient phase.

After reaching deflections of nearly 0.35 mm the load, respectively the stress level, hardly decreases up to deflections of 1.0 mm. This behaviour could be explained in terms of steel fibre bridging and stress transfer from the concrete matrix to the fibres by friction.

At 600 °C and 800 °C the matrix contains a lot of cracks. Already low bending tensile forces lead to a collapse of the plain concrete. In the fibre concrete, the steel fibres are partially activated in a very early phase and fully activated after deflections of nearly 0.2 mm. For the 600 °C-specimens the stress from the fibres to the matrix is transferred by friction. - The fibres are pulled-out of the matrix at very high deflections, respectively crack mouth opening displacements. The 800 °C-specimens show a somewhat different behaviour. At 800 °C the steel fibres are already very soft and the friction forces are higher than the tensile strength of the fibres, so they fail in tension, if crack mouth opening of 0.25 mm is exceeded.

4. CONCLUSIONS

From the results obtained it can be concluded: High temperature as well as low temperature exposure leads to a significant reduction of the bending tensile strength of both plain concrete and fibre reinforced concrete. This is caused mainly by formation of cracks especially in the contact zone between the coarse aggregates and the fine grained mortar matrix due to thermal incompatibilities of cement paste and aggregates. Steel fibre reinforcement imparts a well defined post-cracking behaviour to the composite and increases the post maximum ductility. At high temperatures the stress transfer from the fibres to the matrix is caused mainly by frictional forces, this holds for low temperature damaged concrete, too. At ambient temperature the main stress transfer mechanism is friction. Adhesion is relevant only up to the onset of matrix failure.

REFERENCES

1. ROSTASY, F.S.; WIEDEMANN, G.: Festigkeit und Verformung von Beton bei sehr tiefer Temperatur. Beton 2/80.
2. ROSTASY, F.S.; SPRENGER, K.H.: Strength and Deformation of steel fibre reinforced concrete at very low temperature. The International Journal of Cement Composites and Lightweight Concrete, Volume 6, No. 1, February 1984.
3. DIEDERICHS, U.; SCHNEIDER, U.: Pilotstudie zum Spannungs-Dehnungs- und Warmkriechverhalten von Stahlfaserbeton. Bericht aus dem Teilprojekt B 3 des Sonderforschungsbereichs 148 "Brandverhalten von Bauteilen" der Technischen Universität Braunschweig. Braunschweig, 1979 (unveröffentlicht).
4. KORDINA, K.; WYDRA, W.; DIEDERICHS, U.: Untersuchungen zur Biegezugfestigkeit von thermisch hochbeanspruchtem Stahlfaserbeton. Bericht des Instituts für Baustoffe, Massivbau und Brandschutz, Technische Universität Braunschweig, August 1986.