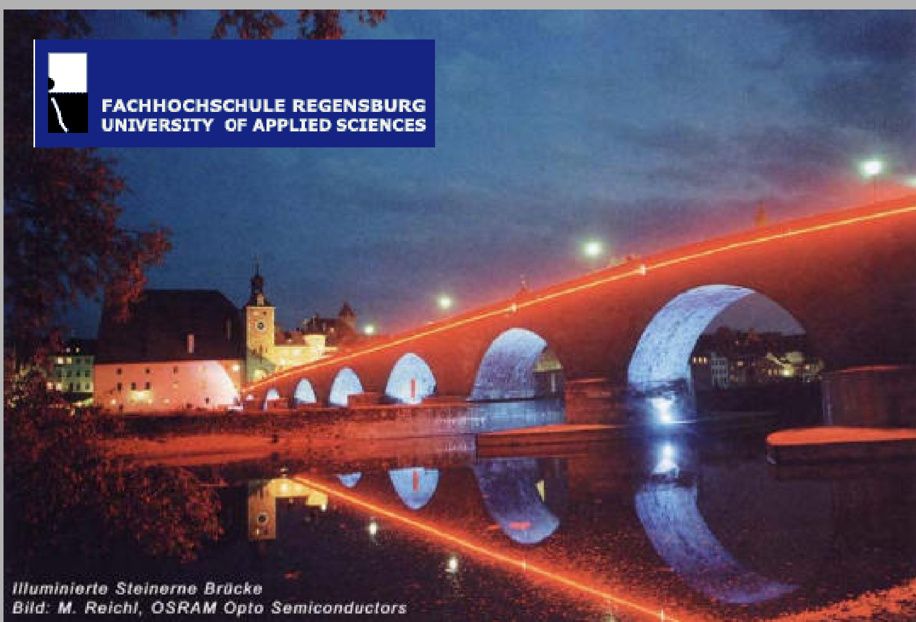
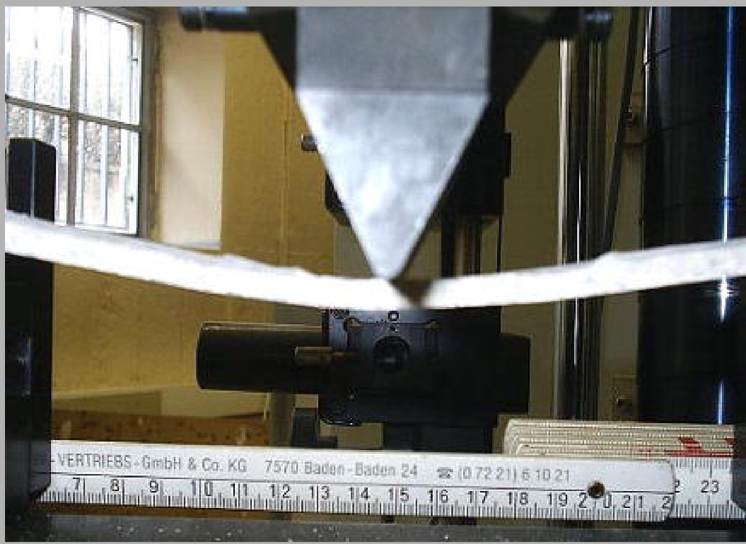
Fibre reinforced concrete
- requests and facts

Wolfgang Kusterle
Regensburg University of Applied Sciences



“DUCTILE CONCRETE“

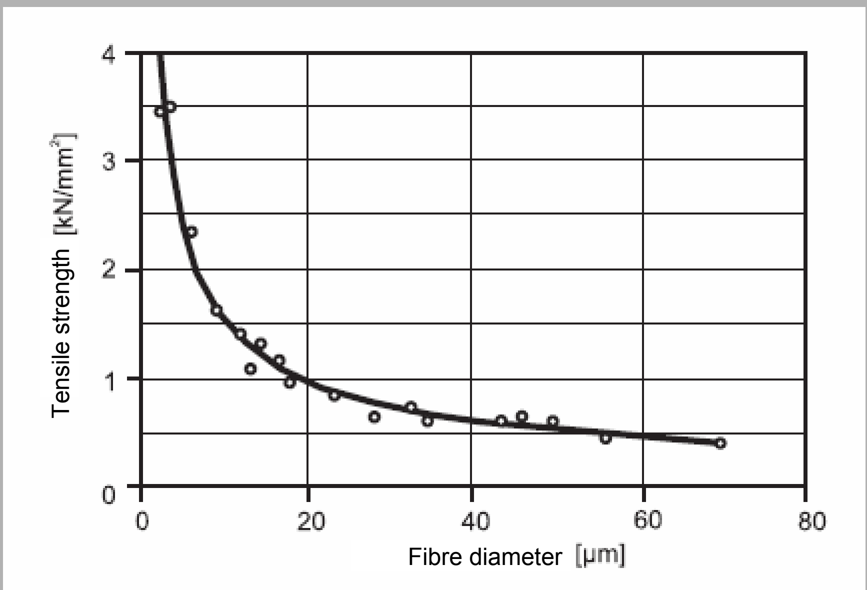


CONTENT

- Fibre composite materials
- Fibres
- Application of fibres
- Testing FRC
- Post tensioning behaviour
- Advantages of multiple cracking
- Flexural creep

SOME BASICS ON FIBRE-REINFORCED COMPOSITE MATERIALS

- Paradox of solid materials (Zwicky, 1923)
- Paradox of fibre dimensions (Griffith, ca. 1920)
- Paradox of length of fibres
- Paradox of 2-phase composites (Slayter, 1962)

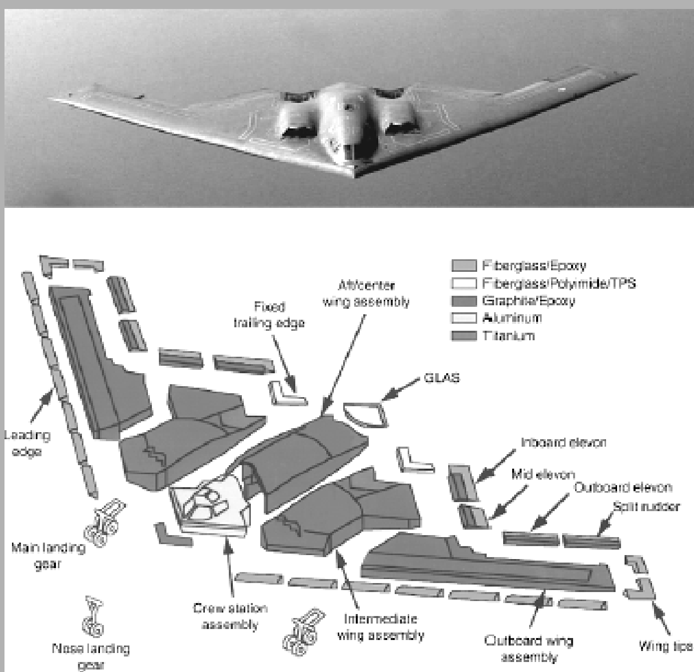


Requirements for an optimum performance of the composite

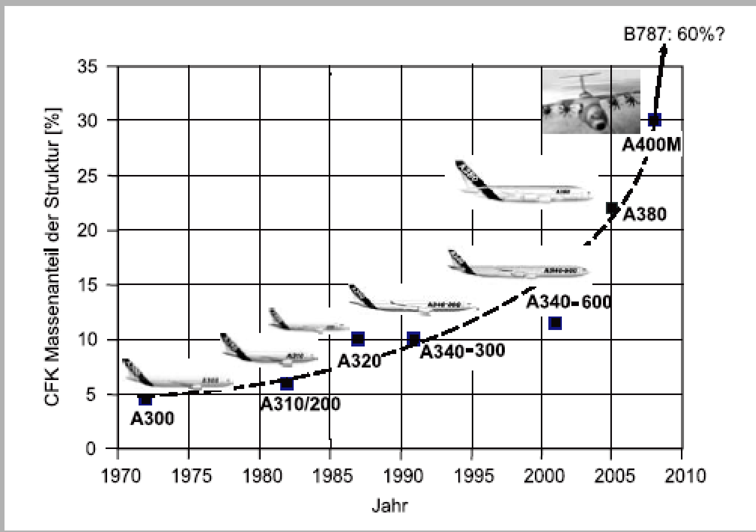
$E_{fibre} > E_{matrix}$

$\varepsilon_{rupture,\ matrix} > \varepsilon_{rupture,\ fibre}$

$R_{max,\ fibre} > R_{max,\ matrix}$



CFK use in aircraft industry in % of structure



TYPES OF FIBRES

Natural fibres
Man-made fibres

• Metall	
• Synthetic polymer fibres	PP PE PVA Acrylic polymers ….
• Carbon	
• Glass	
• Mineral fibres	aspestos basalt
• Natural plant fibres	cotton linen sisal …..
• Wood fibres	
• Animal fibres	

Steel fibres

Steel wire fibres
Slit sheet steel fibres
Mill cut fibres
Melt extract fibres
Corrugated fibres

Fibre form

Straight
Hooked ends
Enlarged ends
Cottugated
Crimped
embossed

Cross-section

Round
Rectangular
Crescent

Glued to bundles

Low carbon, high carbon steel, galvanized, stainless steel


STABILA


STABILA

Polymer micro fibres

Multifilament, monofilament,
round cross section, extruding procedure

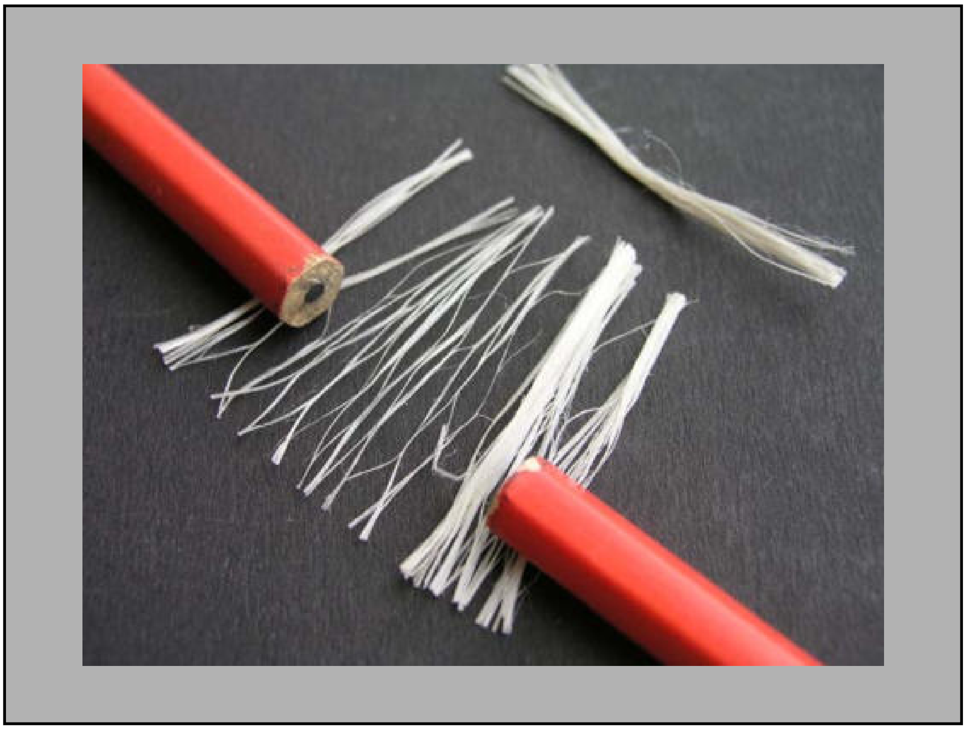
Fibrillated, cut from sheets, rectangular

Structural syntetic fibres

High strength, high modulus synthetic macro fibres

Glass fibres

AR-glass



Aspect ratio
Length to diameter ratio

The higher the aspect ratio, the better the performance
Critical fibre length (failure mode: extraction – fibre rupture)

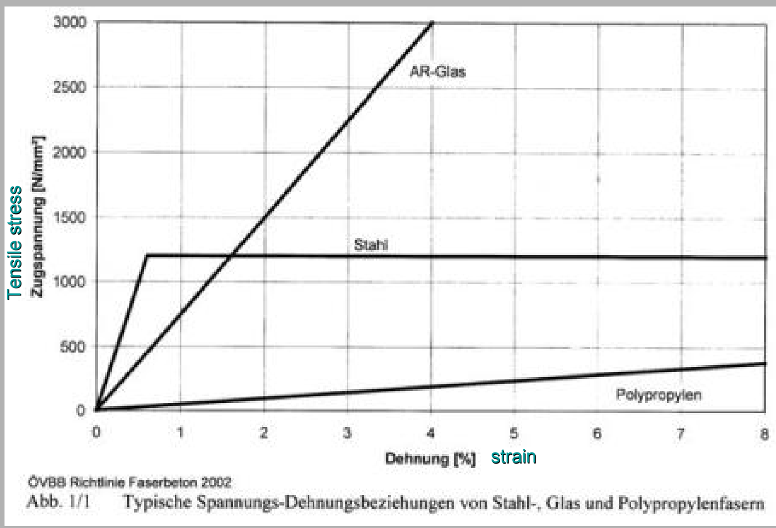
Performance depends on
Dosage
Fibre parameters (Aspect ratio, tensile strenghts, anchorage, bond performance, elongation at rupture)

Homogeneous distribution - fibre balling

Comparison of Different Fiber Types:

	Tensile strength (MPa)	Elongation (%)	Tensile modulus (GPa)	Specific Gravity (g/cm3)	Durability	Affinity to cement	Cost performance	Remarks
PVA-fiber	880-1600	6-10	25-41	1.3	E	E	E	-
PP	600	25	5	0.95	G	N	G	Floats in water
HCPE	2700	5	120	0.98	G	N	N	Expensive
Aramide	3000	4	100	1.4	N	G	N	Expensive
Carbon	3500	0-2	250	1.7	E	N	N	Expensive
Steel	1200	3-4	200	7-8	G	N	G	Heavy, rusts
ARG	2200	0-4	80	2.5	N	N	N	Weak in alkali

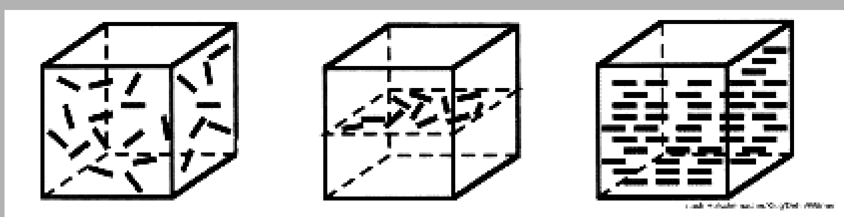
Kuraray



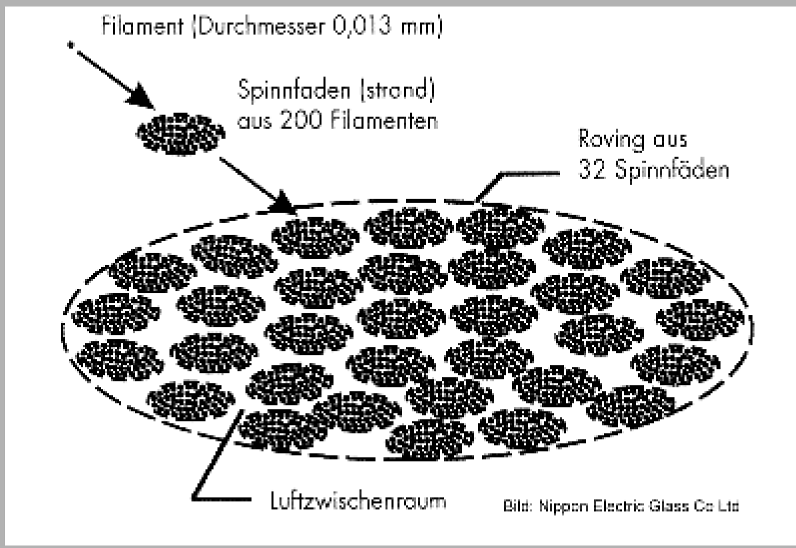
Typical stress-strain relations for steel, glass and PP

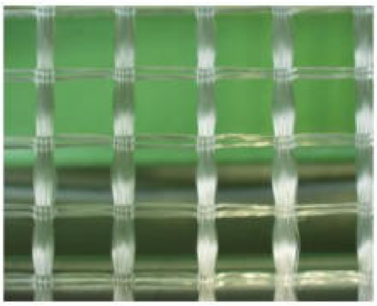
APPLICATION OF FIBRES

Orientation of Single Fibres

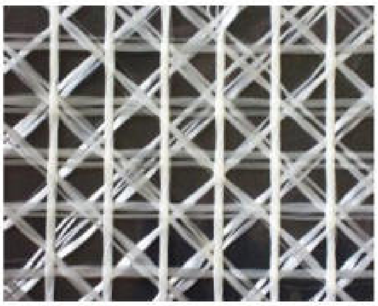


Textile reinforcement





Bidirectional



Multidirectional

CFK –
reinforcement bars

prestressed CFK- elements

Application areas for fibre reinforced concrete

- reduction of early shrinkage cracks
- reduction of spalling in case of fire
- structural use, reinforcement, „toughness“

Specific characteristics of FRC

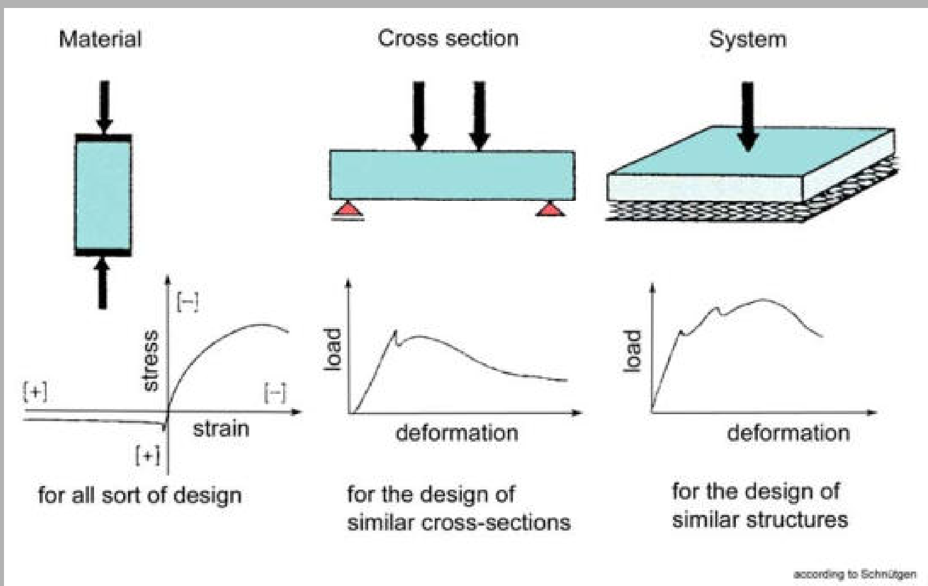
Common fibre content < 1 Vol.-% steel, < 2 Vol.-% polymer

Coarse aggregates

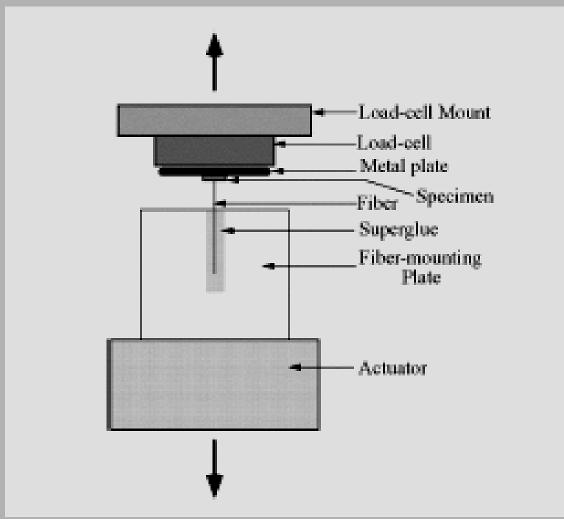
Cement paste (grain size, viscosity, alkality)

Brittle matrix in tension

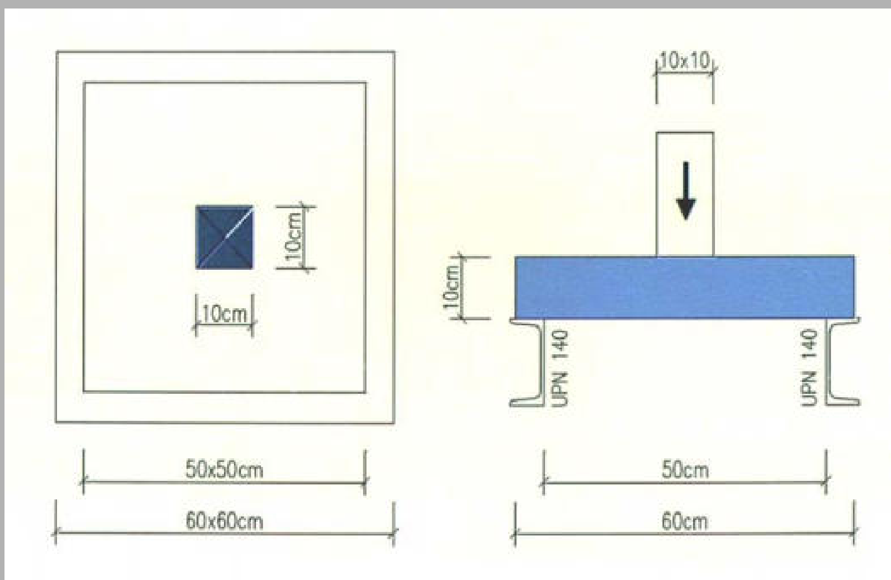
TESTING OF FIBRE REINFORCED CONCRETE (FRC)



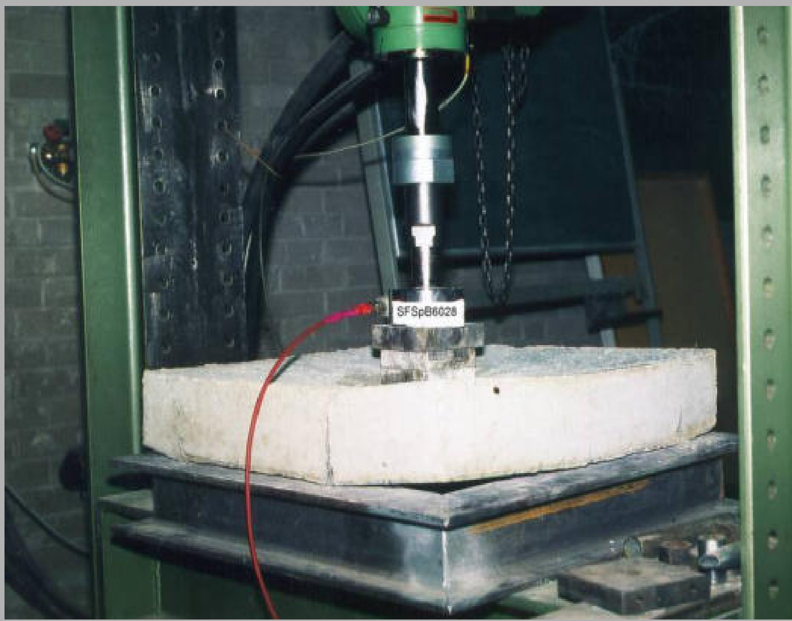
Pull-out test of single fibre

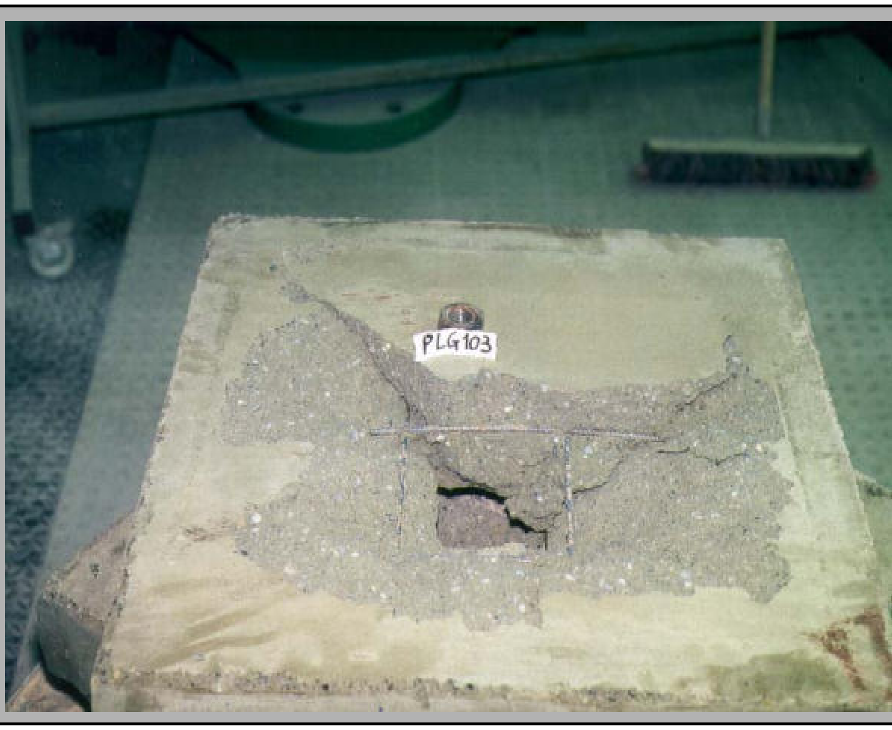


Energy absorbtion capacity of FRC slabs

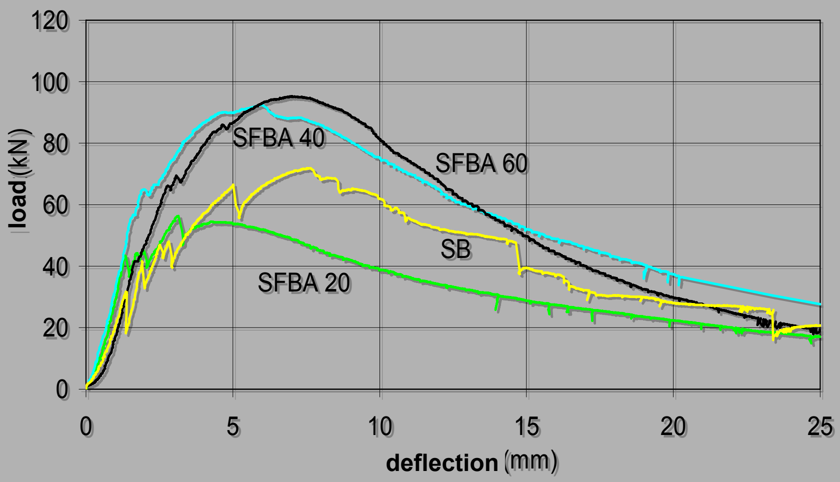


Panel test



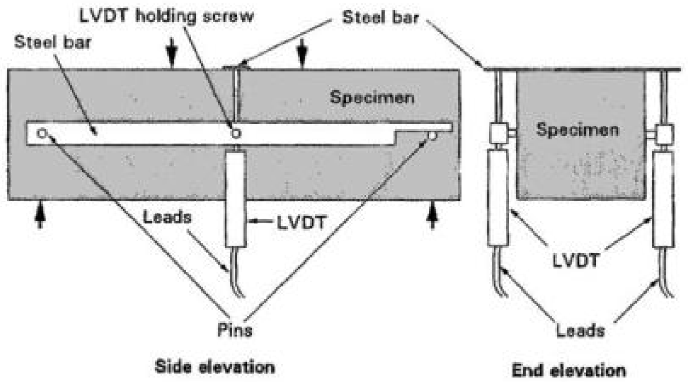

PLG103

Results of slab specimen tests with 20 to 60 kg/m³ of steel fibres (SFBA) and with mesh reinforcement (SB)



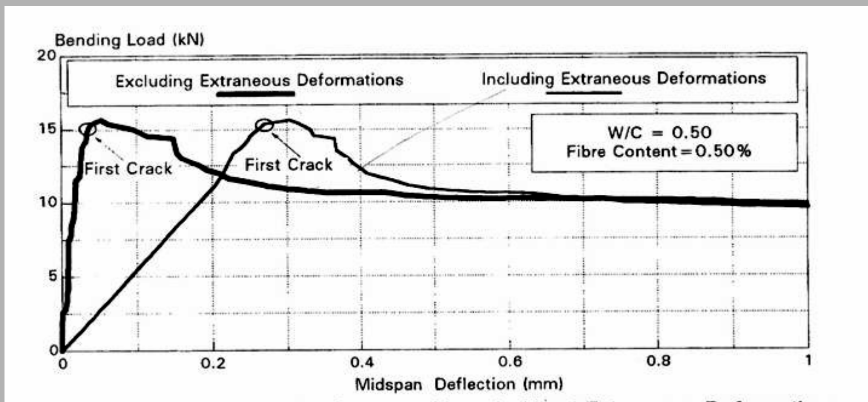
⇒ Calculation of the absorbed energy as a function of the slab deflection

Flexural strength (toughness test)
Beam test



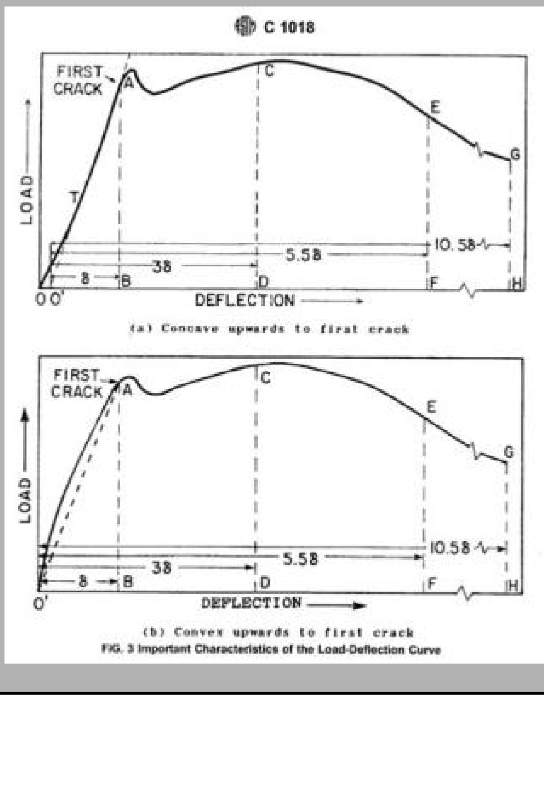
Schematic Illustration of Japanese Yoke Deflection Measuring System

regarding to R. Morgan



Typical Load-Deflection Curves: with and without Extraneous Deformations.

Morgan/Chen / Beaupre

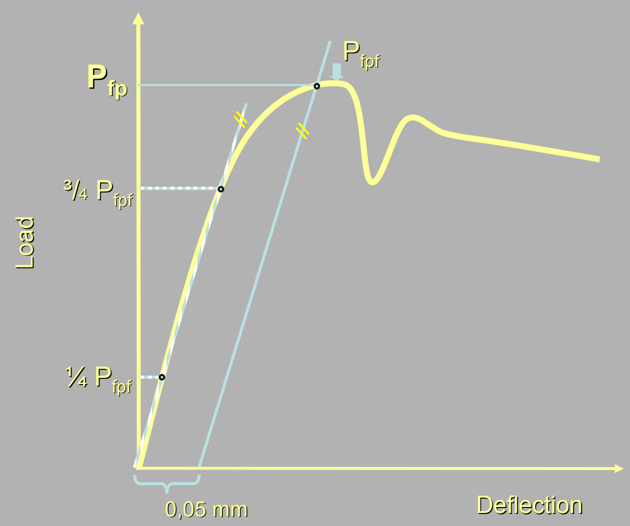


(a) Concave upwards to first crack

(b) Convex upwards to first crack

FIG. 3 Important Characteristics of the Load-Deflection Curve

Definition of first crack



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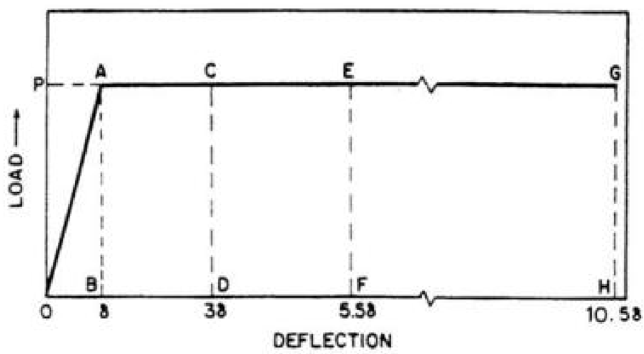
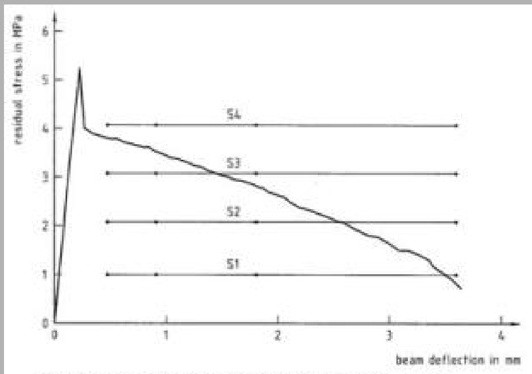


Area Basis[A]	Index Designation	Deflection Criterion	Values of Toughness Indices: Plain Concrete	Elastic-Plastic Material	Observed Range for Fibrous Concrete
OACD	I_5	3δ	1.0	5.0	1 to 6
OAEF	I_{10}	5.5δ	1.0	10.0	1 to 12
OAGH	I_{20}	10.5δ	1.0	20.0	1 to 25

[A] Indices calculated by dividing this area by the area to the first crack OAB.

FIG. X1.1 Definition of Toughness Indices in Terms of Multiples of First-Crack Deflection and Elastic-Plastic Material Behavior



EN 14487-1, Figure A.1 Example of deflection/residual stress curve
residual strength class D1S3 (as well as D2S2 and D2S1)

EN 14487-1 **Table 2 — Definitions of residual strength classes**

Deformation range		Strength level (Minimum strength, MPa)			
	Deflection mm	S1	S2	S3	S4
D1	0,5–1	1	2	3	4
D2	0,5–2				
D3	0,5–4				

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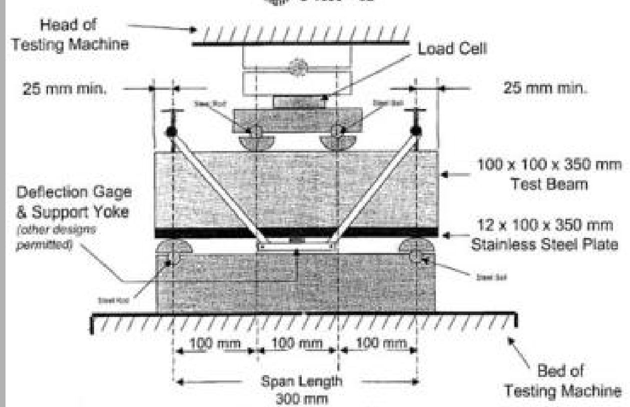


Note: All dimensions are ± 2%

FIG. 1 Schematic of a Suitable Apparatus Where the Deflection Gage Support Frame is Seated on the Beam

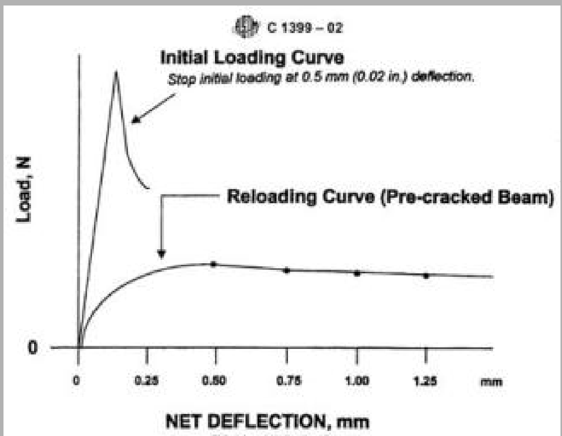
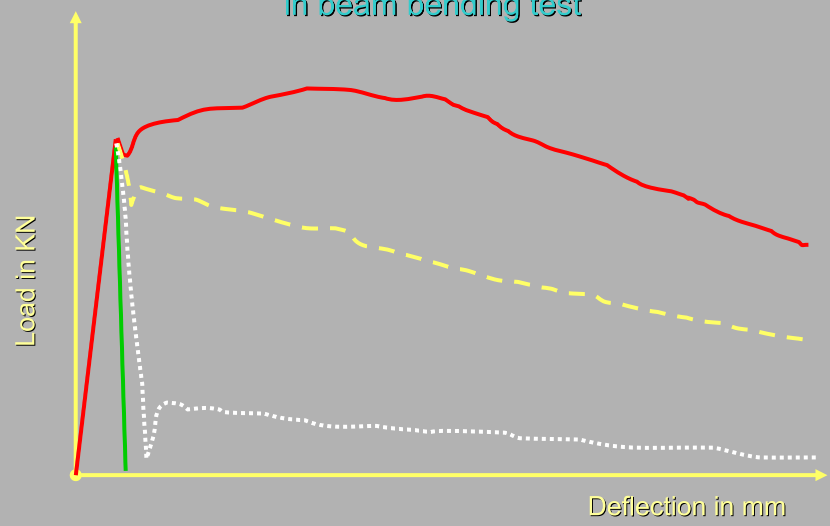
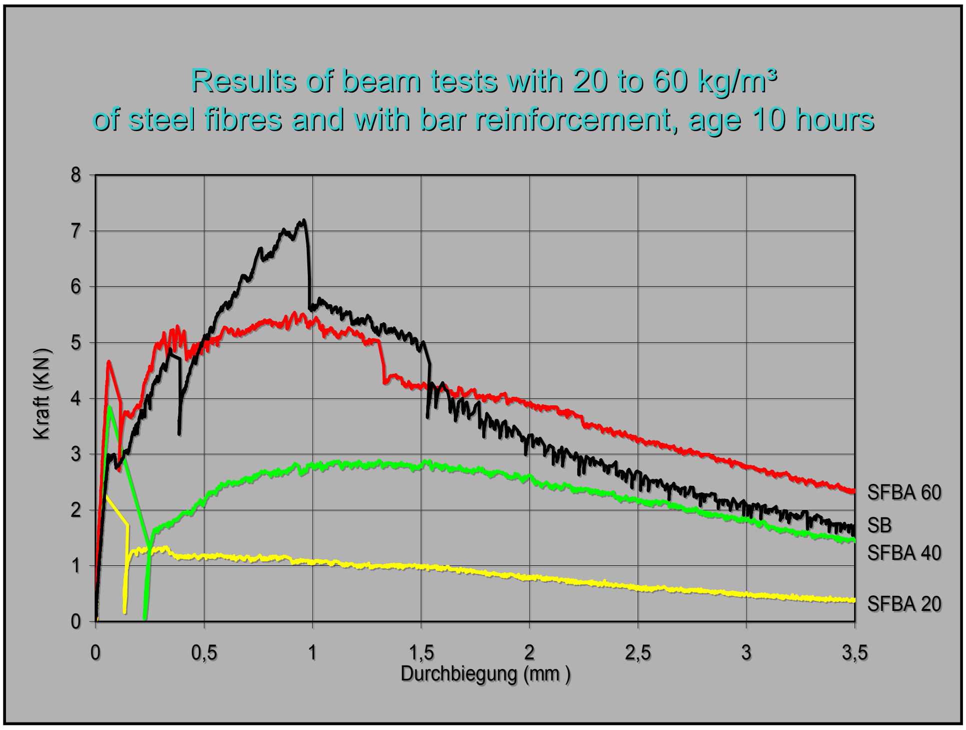


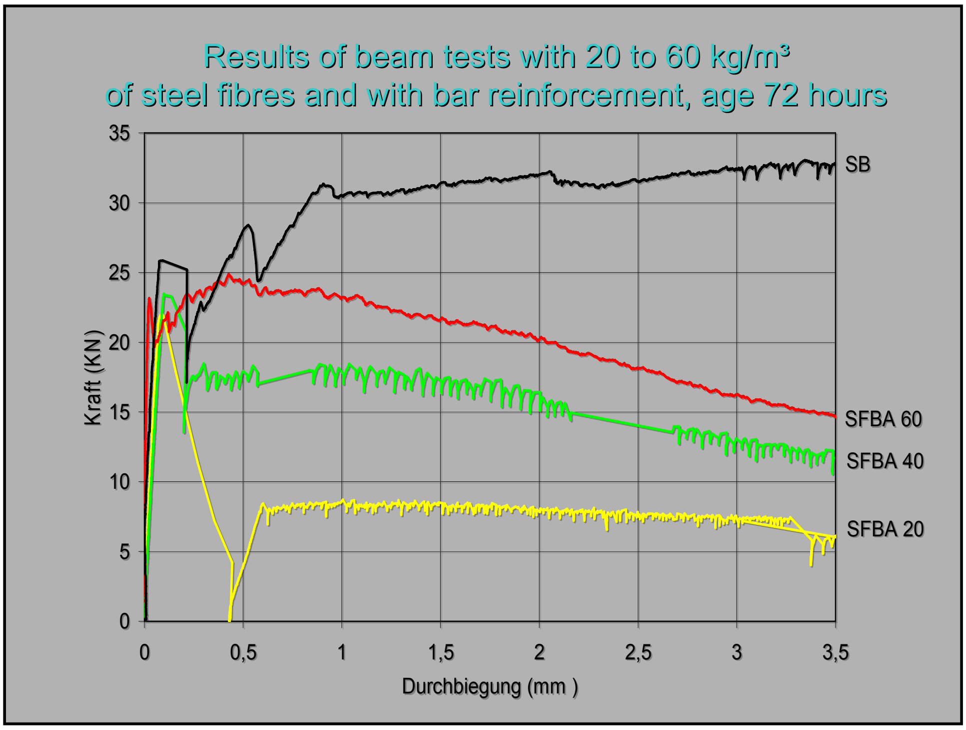
FIG. 3 Load-Deflection Curves

Post crack behaviour of FRC
in beam bending test



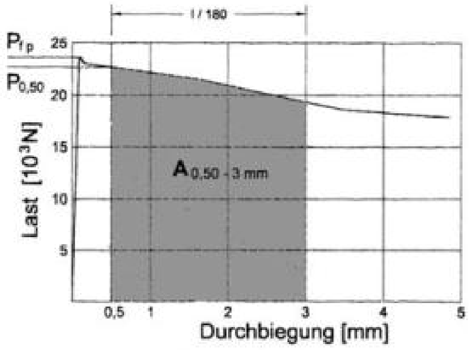


Results of beam tests with 20 to 60 kg/m³
of steel fibres and with bar reinforcement, age 10 hours
Kraft (KN)
0
1
2
3
4
5
6
7
8
0
0,5
1
1,5
2
2,5
3
3,5
Durchbiegung (mm)
SFBA 60
SB
SFBA 40
SFBA 20



Results of beam tests with 20 to 60 kg/m³
of steel fibres and with bar reinforcement, age 72 hours
Kraft (KN)
0
5
10
15
20
25
30
35
0
0,5
1
1,5
2
2,5
3
3,5
Durchbiegung (mm)
SB
SFBA 60
SFBA 40
SFBA 20

ÖVBB



Gebrauchstauglichkeit (TG)

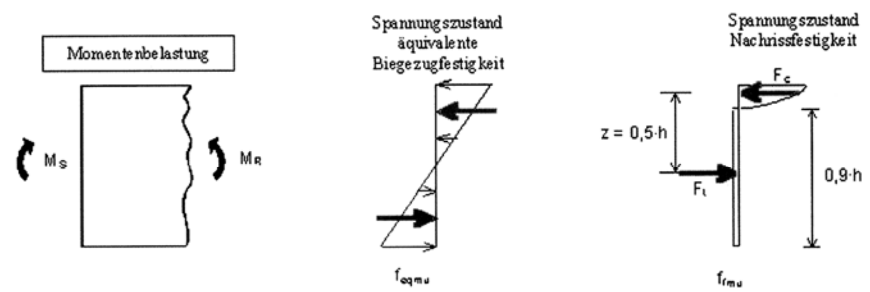
$$f_{eqms} = \frac{P_{0,50} \times l}{b \times h^2} = \frac{P_{0,50}}{7500} \, [N/mm^2]$$

Tragsicherheit (T)

$$P_{0,50-3\,mm} = \frac{A_{0,50-3\,mm}}{l / 180} = \frac{A_{0,50-3\,mm}}{2,5} \, [N]$$

$$f_{eqmu} = \frac{P_{0,50-3\,mm} \times l}{b \times h^2} = \frac{P_{0,50-3\,mm}}{7500} \, [N/mm^2]$$

Äquivalente Biegezugfestigkeit (Durchbiegung bei einer Spannweite von 450)



Umrechnung von äquivalenter Biegezugfestigkeit in die Nachrisszugfestigkeit

Burtscher/Kollegger

$$M_{R,eq} = f_{eqmu} \cdot \frac{b \, . \, h^2}{6}$$

$$M_{R,fmu} = f_{fmu} \, . \, b \, . \, 0,9 \, . \, h \, . \, 0,5 \, . \, h$$

$$f_{fmu} = 0,37 \, . \, f_{eqmu}$$

$$f_{fmu} = f_{eqmu} \cdot 0{,}37$$

$$f_{fku} = f_{fmu} \cdot 0{,}71$$

$$(f_{fku} = f_{fmu} \cdot 0{,}78)$$

statistic

Design:

$$f_{fdu} = \frac{f_{fku}}{\gamma_c} = \frac{f_{fku}}{1{,}5}$$

Design values regarding ÖVBB guideline FRC, 2002

ÖVBB- Richtlinie Faserbeton 2002

Tab. 7/1 Faserbetonklassen und Bemessungswerte der Nachrisszugfestigkeiten f_{fdu} [N/mm²] für den Nachweis der Tragsicherheit

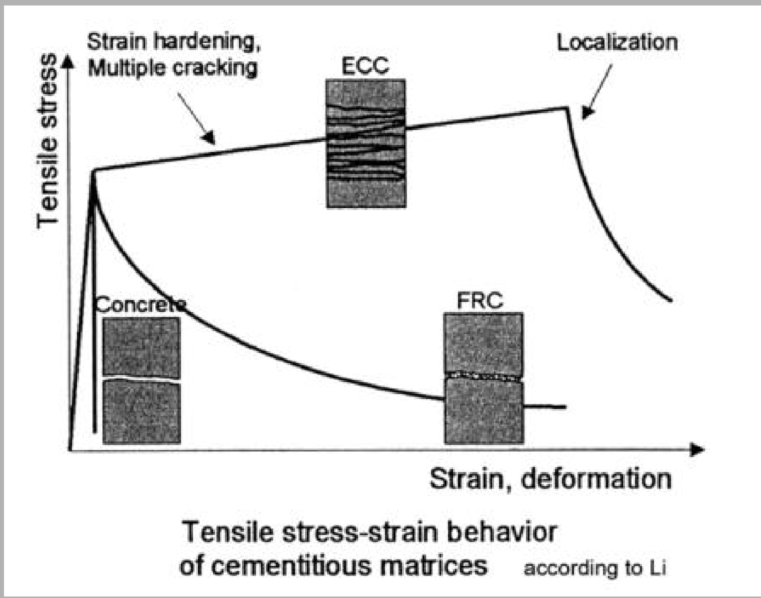
Faserbetonklasse	Mittlere äquivalente Biegezugfestigkeit f_{eqmu} [N/mm²]	Bemessungswert der Nachrisszugfestigkeit f_{fdu} [N/mm²]	
		Bauteil b ≤ 10 h	Bauteil b > 10 h
T Sonderklasse	5,00	0,86	0,96
T5	3,50	0,60	0,67
T4	2,75	0,48	0,53
T3	2,00	0,35	0,38
T2	1,25	0,22	0,24
T1	0,50	0,09	0,10

test result design value

POST TENSIONING BEHAVIOUR

- Development of a mortar or concrete with multiple-crack pattern in bending test

Crack pattern



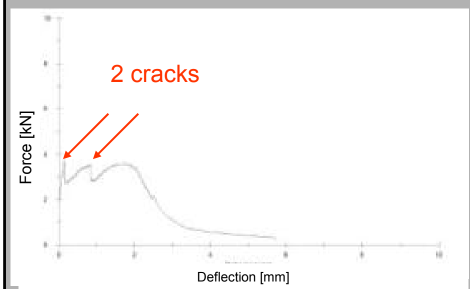
Toughness tests

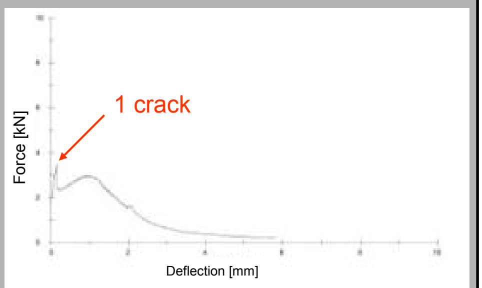
- Age of the samples 14 days
- Water storage

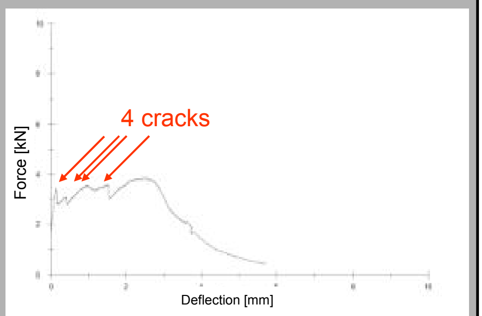
Toughness tests

Test procedure

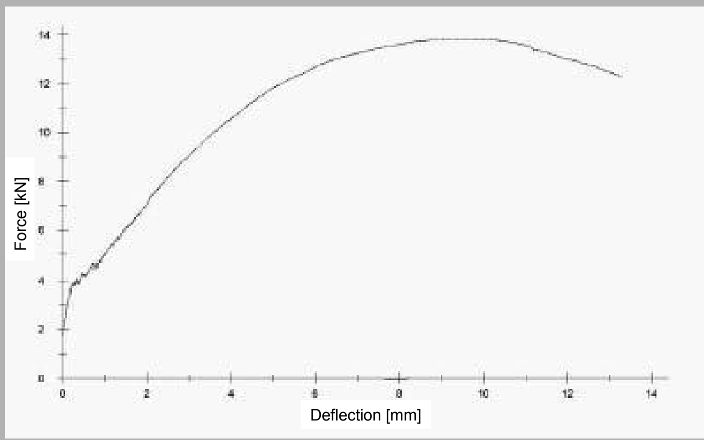
- Measuring yoke is fixed on concrete beam (150 x 50 x 700 mm)
- Level the sample axial under the force discharges
  - Distance between supporting rollers = 600 mm
  - Distance between the single force discharges = 200 mm





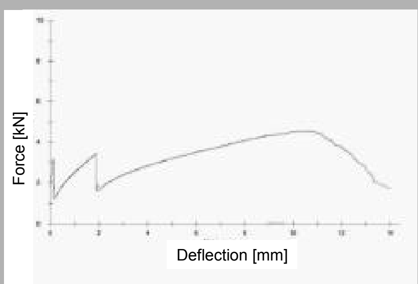


Identification of cracks in load-deflection curve

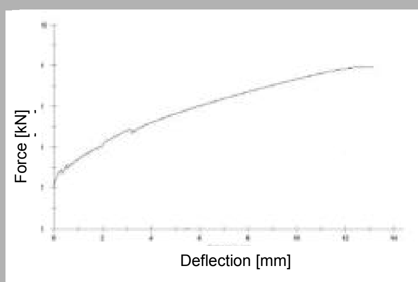


Cement-infiltration-methode: up to 70 cracks

Effect on the post-crack-behavior by using compounds of reinforcing mesh and fibres



mix 23
5 sheets glass fibre mesh
2 cracks



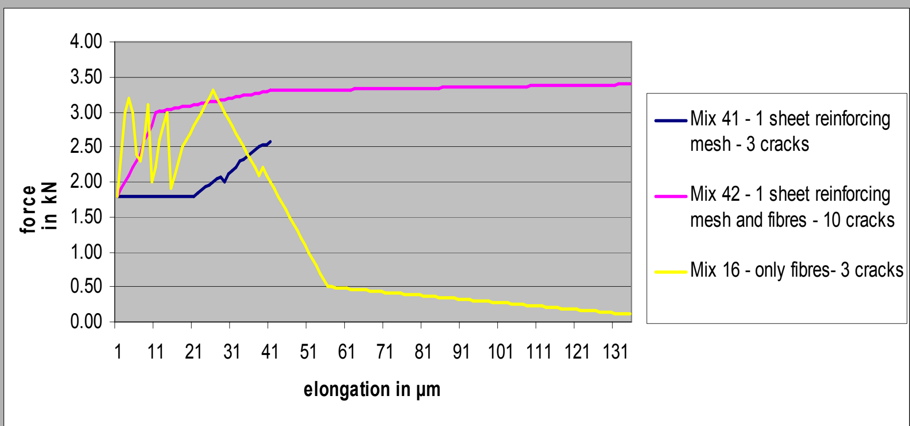
mix 24
5 sheets glass fibre mesh
2 Vol% PVA-fibres
7 visible cracks

Mix design of selected mixes

material	150x50x700	150x50x700	150x50x700
	mix 16	**mix 41**	**mix 42**
OPC	1.0	1.0	1.0
PFA	0.3	0.3	0.3
dried silika sand	0.8	0.8	0.8
fibres	0.02		0.02
reinforcing mesh		1 sheet	1 sheet
water	0.45	0.45	0.45
plasticiser	0.0075		0.0075
stabilizer	0.0005		0.0005

Toughness tests

Samples 150 x 50 x 700 with reinforcing mesh and fibres

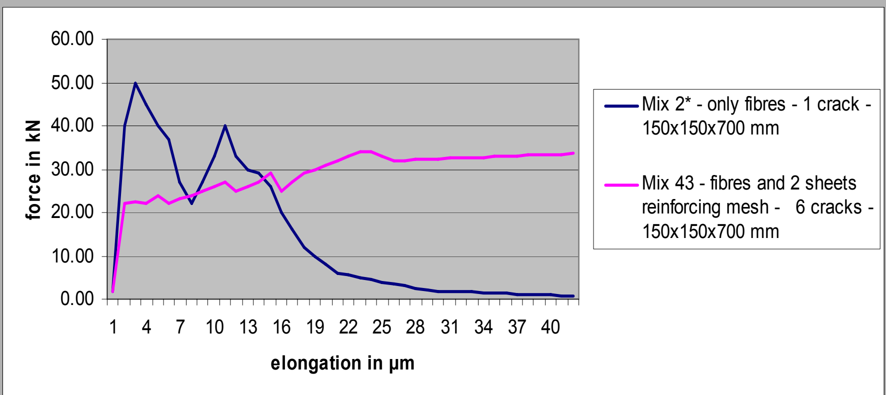


Mix design of selected mixes

material	150x150x700	150x150x700
	mix 2*	**mix 43**
OPC	1.0	1.0
PFA	0.3	0.3
dried silika sand		0.8
granite fines sand	0.8	
fibres	0.02	0.02
reinforcing mesh		2 sheet
water	0.45	0.45
plasticiser	0.0075	0.0075
stabilizer	0.0005	0.0005

Toughness tests

Samples 150 x 150 x 700 mm with PVA mesh and PVA fibres



Mix 14 – 1 crack

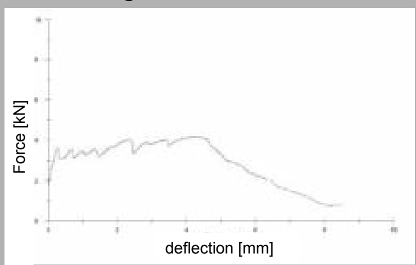
Mix 9 – 1 wider crack, some more cracks

Mix 8 – 1 wider crack, many other cracks

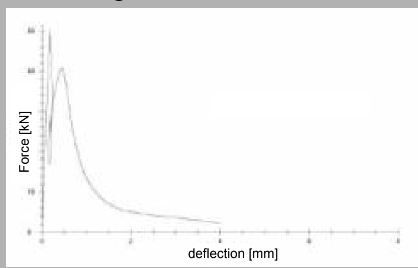
Mix 18 – many small cracks

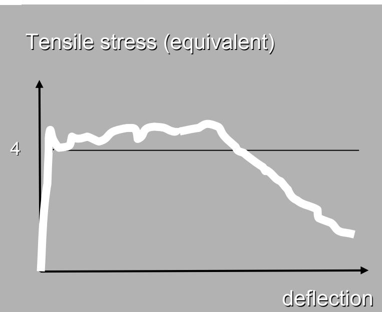
Sifcon 2 – over 70 small cracks

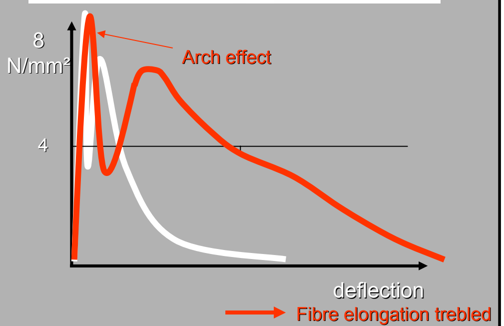
mix 2, hight of beam **50 mm**



mix 2, hight of beams **150 mm**

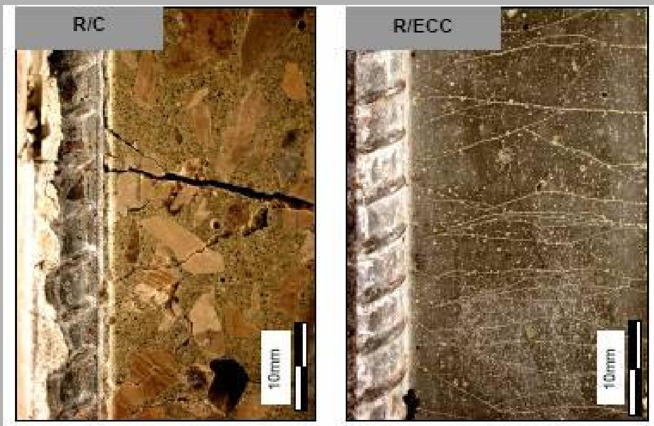


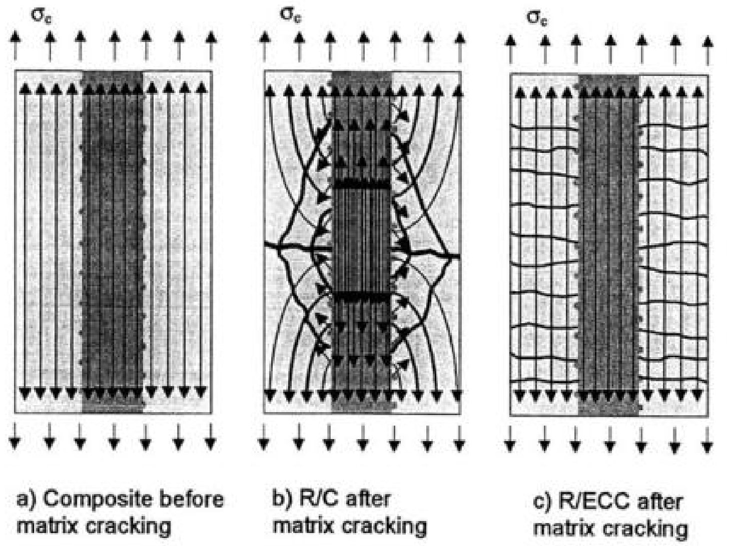




ADVANTAGE OF MULTIPLE CRACKING OR POST-TENSIONING BEHAVIOUR

Stabel plastic hinges
Dense structures – pollutants
– Water

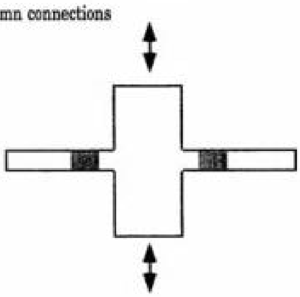


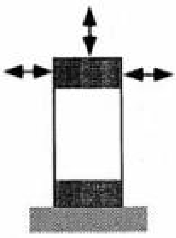


Crack formation and internal stresses in R/C and R/ECC according to Li

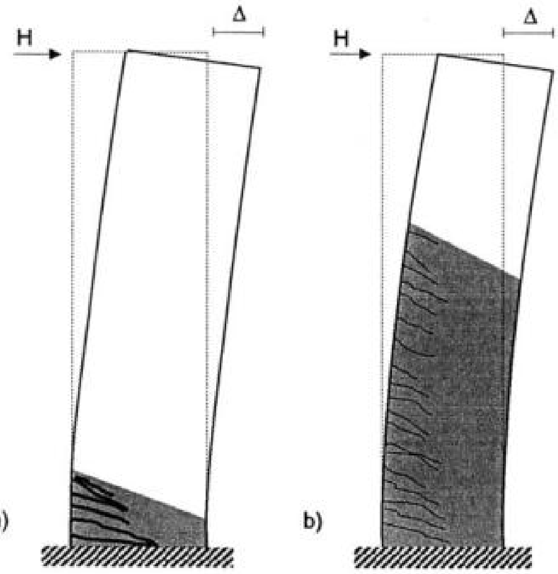
Failure Modes of Typical Structural Members and Performance Improvements by Fiber

Structural Member/Load	Example Application	Performance Modification by Fiber
Beam-column connections	Building frames	Seismic resistance Reduce reinforcement and congestion
Column	Building columns Bridge columns	Seismic resistance Reduce spalling and enhance steel confinement





according to Li



Idealized flexural deformation behavior of
a) R/C and b) R/ECC
according to Li

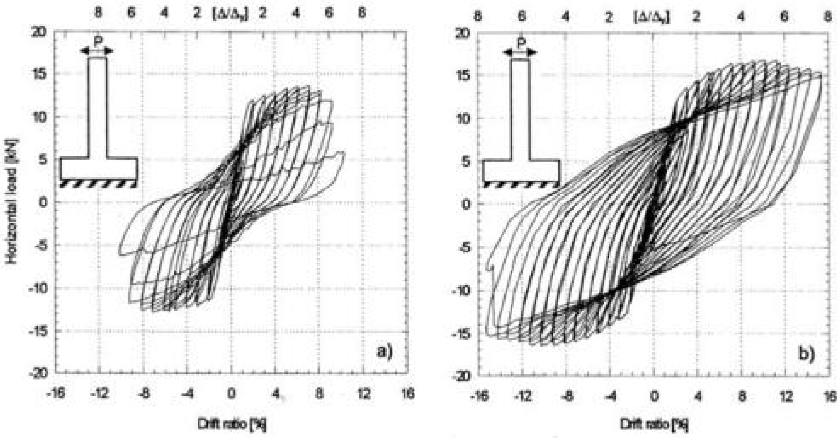
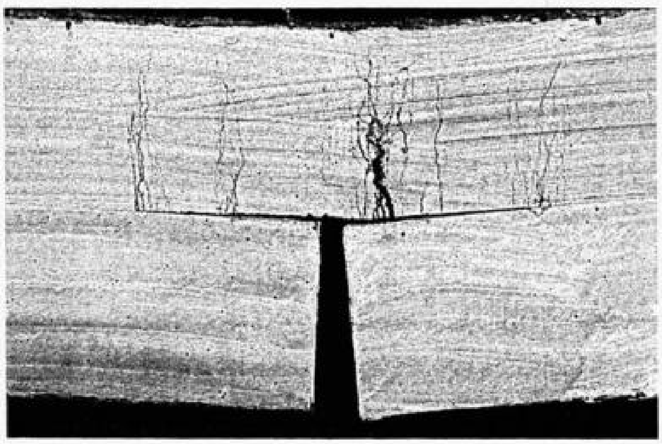


Fig.10 Load-deformation response of a) R/C and
b) R/ECC cantilever specimens with steel reinforcement according to Fischer and Li

Durable Overlay Systems with Engineered Cementitious Composites (ECC)



Close-up view of the kink-trap mechanism in the PE-ECC/PC overlay system according to Li

FLEXURAL CREEP OF FRC WITH STRUCTURAL POLYMER FIBRES

Fibres tested

Durus KrampeHarex Strux Forta

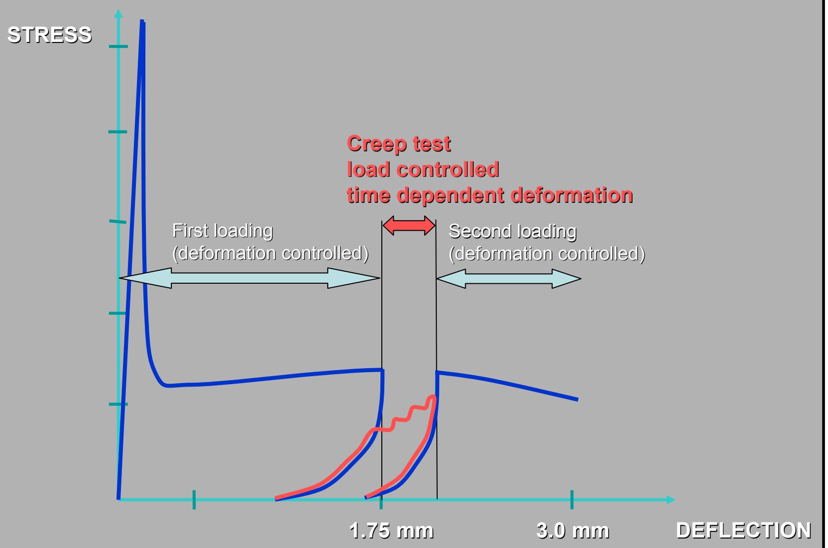
Mix design

370 kg/m³ CEM II A-S / 42.5 R
1747 kg/m³ Donau sand and gravel 0/16
w / c = 0.5
Viscocrete 1020X

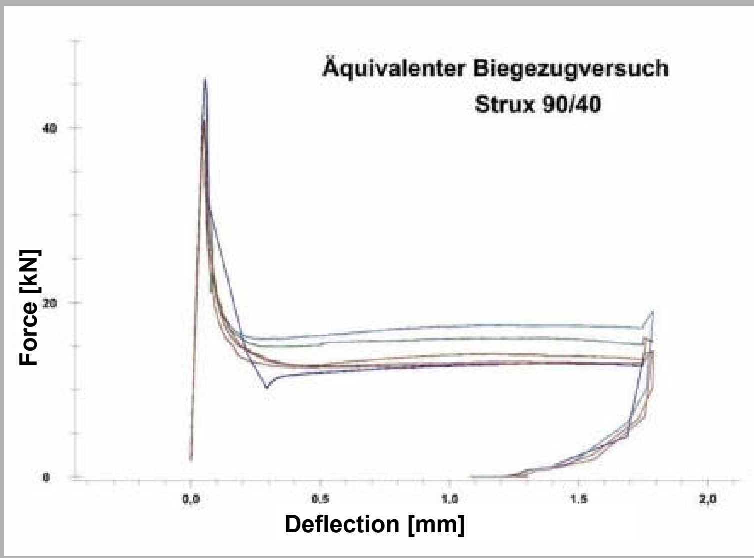
Fibre dosage and fresh concrete properties

Dos.	Fibres	Dos. HRWR	Spread
4.5 kg/m³	Strux 90/40	0.38 %	440 mm
30.0 kg/m³	Steel-Fibre FX 50/1.00	0.25 %	460 mm
4.5 kg/m³	Durus PMW 50/1000-K1,2x1,0R	0.25 %	450 mm
4.5 kg/m³	Forta PF 54/300-K1	0.65 %	450 mm

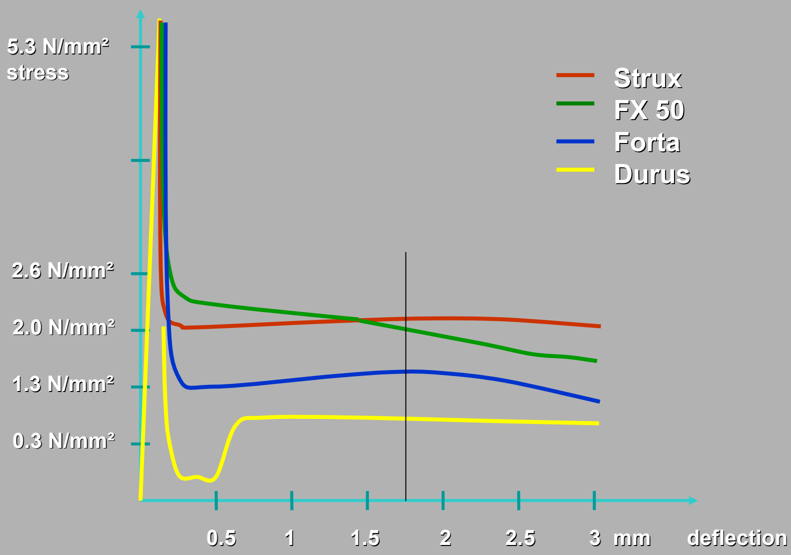
Order of test procedure
toughness test – creep test – toughness test



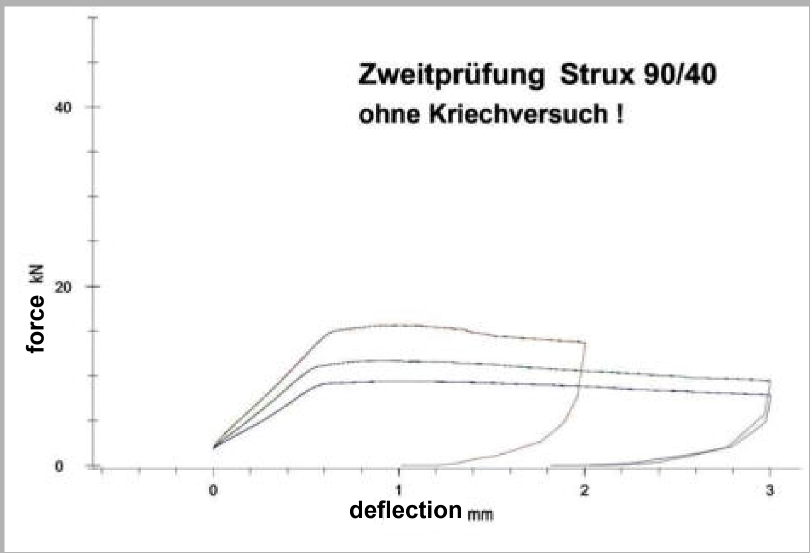
Toughness Test



Stress- Deflection- Diagram

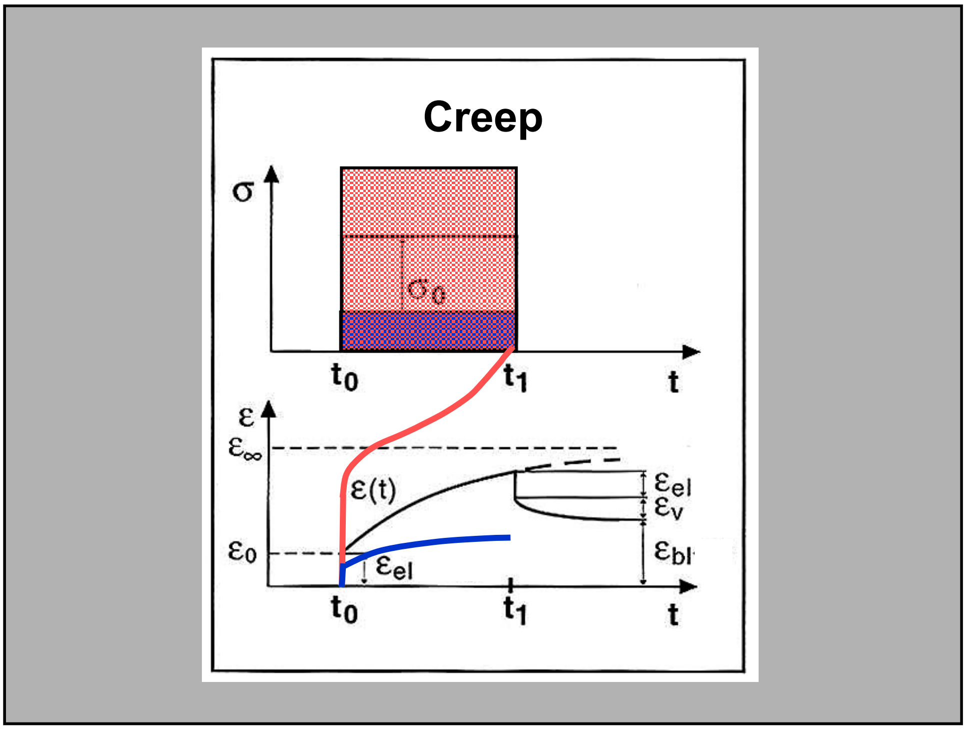


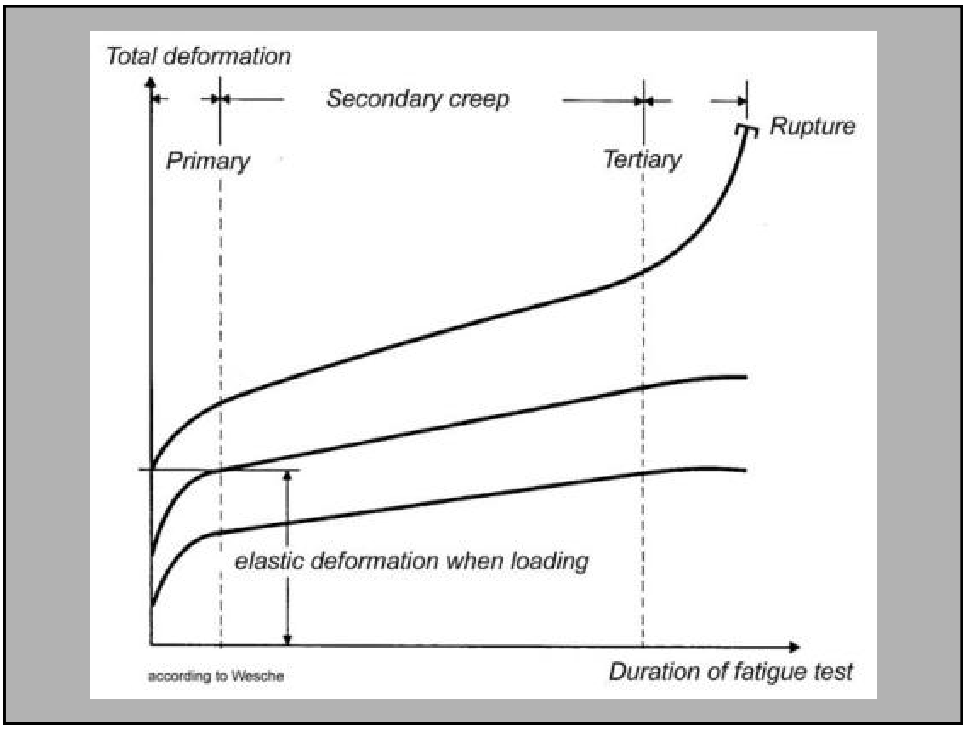
Second Toughness Test (without creeping)



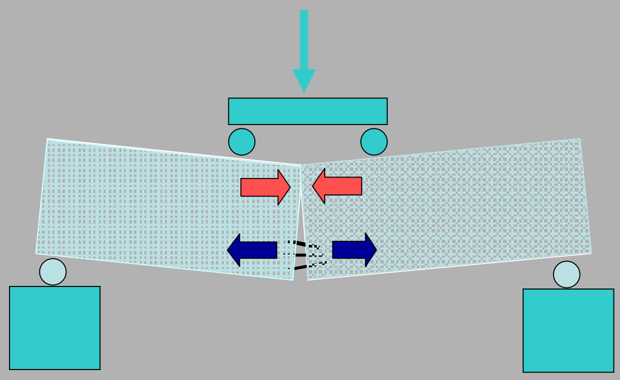
Deformations during deloading and reloading

FIBRE	Deflection during load relieving	Deflection during load reapplication
Strux	0.55 mm	0.55 mm
FX 50	**0.15** mm	**0.15** mm
Forta	0.55 mm	0.50 mm
Durus	0.55 mm	0.50 mm

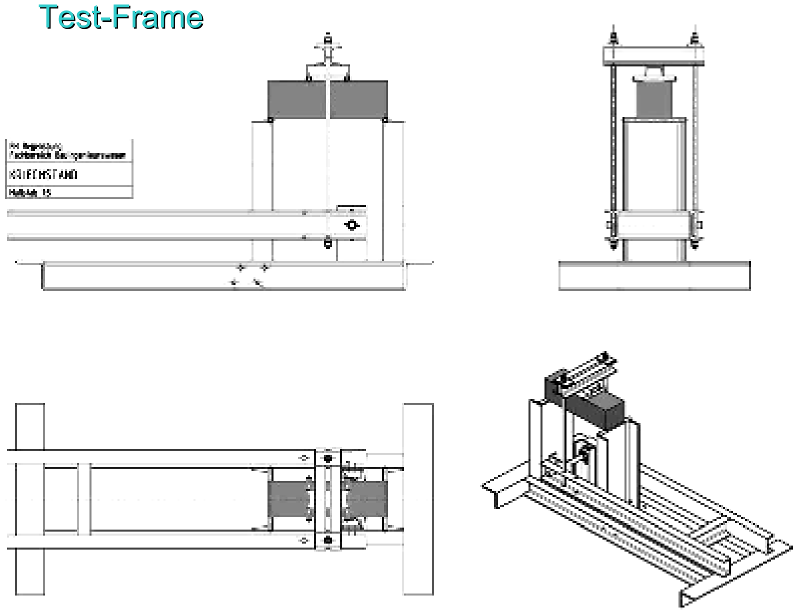

Creep
σ
σ0
t0
t1
t
ε
ε∞
ε(t)
ε0
εel
εel
εv
εbl
t0
t1
t


Total deformation
Secondary creep
Primary
Tertiary
Rupture
elastic deformation when loading
according to Wesche
Duration of fatigue test

Flexural creep of fibre-reinforced concrete



Test-Frame



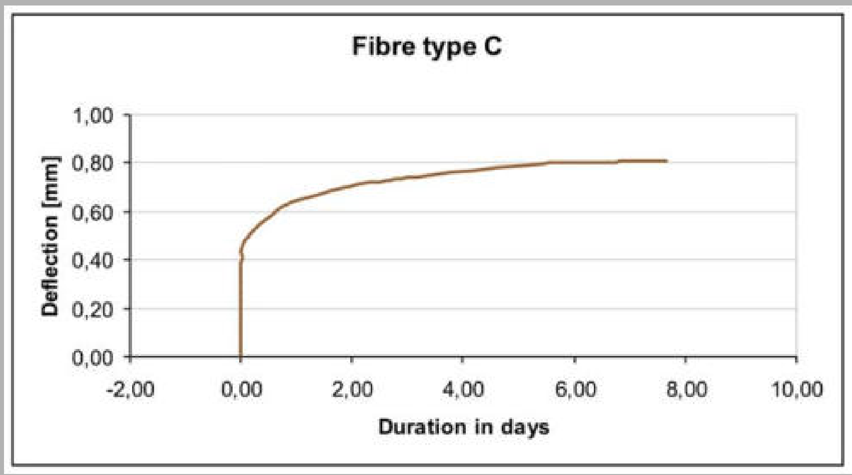

526.0

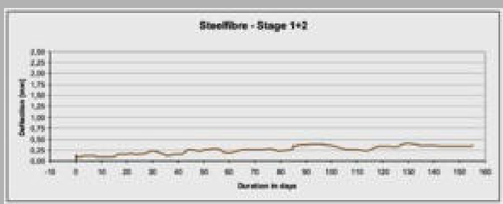
Load Stages in the Creep-Test

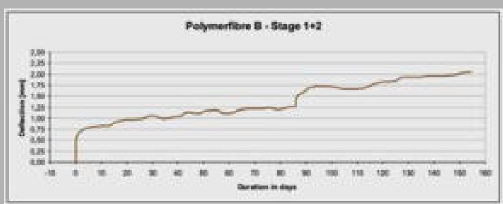
1. Stage 0.47 x $P_{1,75}$
2. Stage 0.60 x $P_{1,75}$
3. Stage 0.71 x $P_{1,75}$
4. Stage 0.85 x $P_{1,75}$

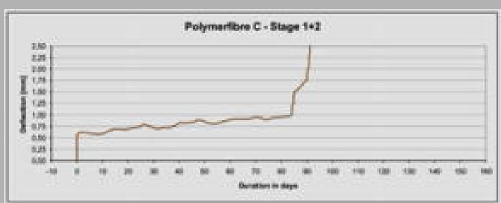
Duration: 3 month each

Creep Stage 1; fibre C



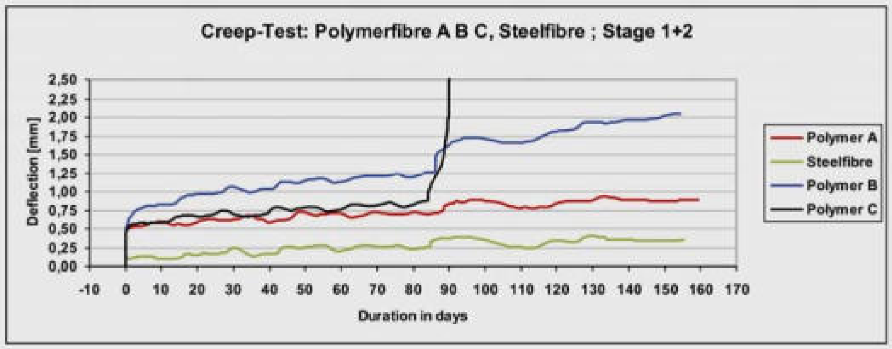






Creep
Stage 1 + 2

All tested fibres, steel and polymer
Stage 1 + 2

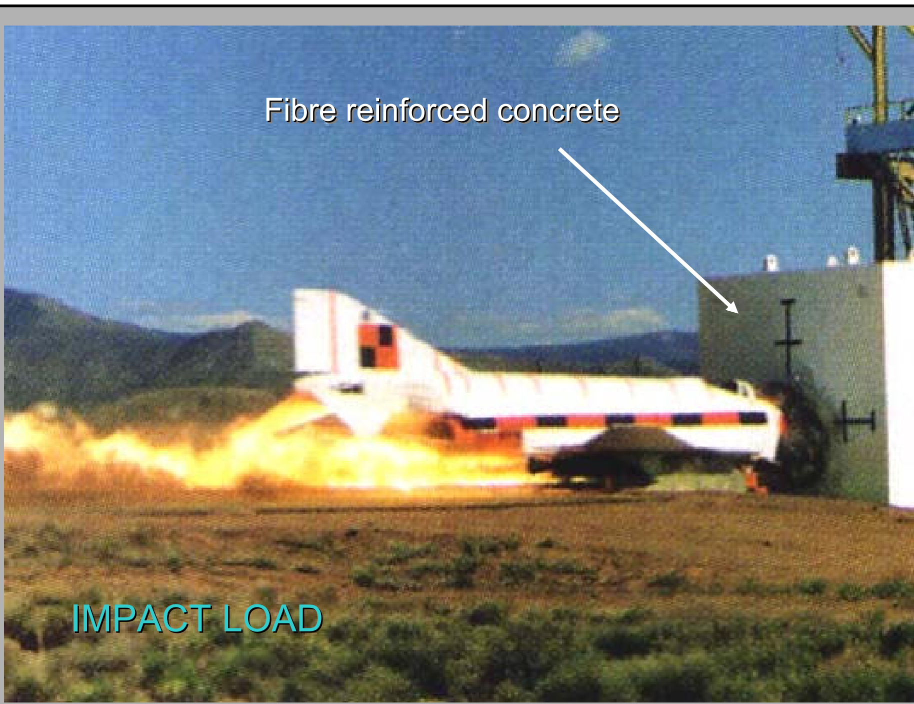


YOUNG FIBRE-REINFORCED CONCRETE

Testing crack formation
due to drying shrinkage

WORKABILITY

FIRE:
Preventing explosive spalling



HEALTH AND ENVIRONMENT

NOTHING IS MORE SUCCESSFUL THAN SUCCESS !

THANK YOU FOR YOUR ATTENTION !