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INFLUENCE OF DIFFERENT MATERIALS PROPERTIES OF FIBRECONCRETE ON THE BEHAVIOUR OF CONCRETE STRUCTURES

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Abstract

Two types of fibre concrete structures are used for construction. Fibre concrete structures without bar reinforcement and reinforced fibre concrete structures with bar reinforcement. The behaviour of these two types of structures is different likewise as for plain and reinforced concrete structures. The behaviour should be described as simple as possible yet real structural model for analysis of stress fields in critical sections of the structure. The minimum volume ratio of fibres $\rho_{V,f,min}$ to obtain homogenous structural fibre concrete in the member is about 0.5%. The characteristic compressive strengths of plain concrete and fibre concrete referring to test specimens in this paper have been approximately 30MPa.

Keywords: Fibre concrete (FC), reinforced fibre concrete (FRC), plain concrete (PC), reinforced concrete (RC), material properties, strength, cracking

1 Introduction

Fibre concrete (FC) is a structural material is nearly the same cementitious–matrix composite as plain concrete (PC) except for the fibres of different types and forms. Fundamental properties of PC start to change after addition of fibres only when a new homogeneous structural material FC is formed. The minimum limiting volume ratio of fibres in FC $\rho_{V,f,min}$ is approximately 0.5%. The difference in behaviour and the resistance of uncracked FC and PC can be practically ignored for FC with $\rho_{V,f} < \rho_{V,f,min}$. Also the stiffening of cracked zone with fibres after occurrence of the first macro-crack is unreliable. Only for $\rho_{V,f} \geq \rho_{V,f,min}$ the behaviour of FC starts to change comparing with PC both for uncracked and especially for cracked states of FC.

Reinforced fibre concrete (RFC) with bar reinforcement is a structural material whose behaviour is controlled by reinforcing steel strain both in uncracked and especially in post-cracking states of concrete structures. The effect of fibres in the material structure is evidenced by the increase of structural resistance and ductility at ultimate limit states and at the serviceability limit states of cracking. The effect of fibres for the other serviceability limit states is demonstrated by reduction of crack width and also by smaller deformations of structures.

2 Fibre concrete without bar reinforcement

The behaviour of such a structural material is usually tested on beam specimens subjected to bending moment controlled by deflection. Preferable slenderness of specimens is $L/h = 4.0$ (Fig.1).

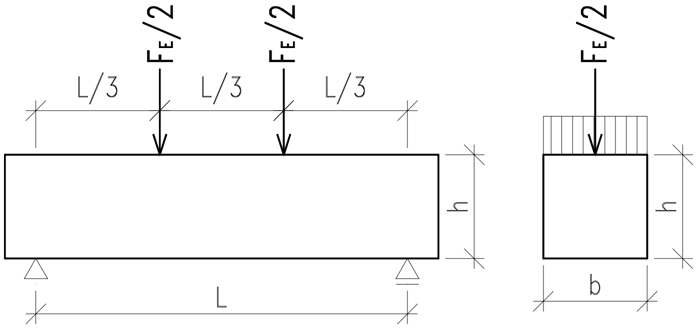


Fig. 1 Setup of the preferable beam specimen for testing ($h = b = 150$mm, $L = 600$mm) subjected to bending moment

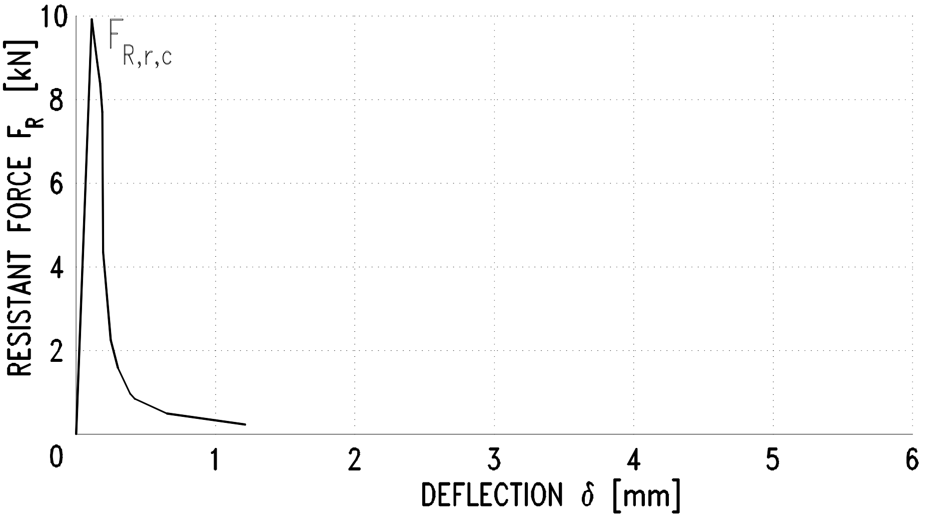
The beam test results in a resistant force–deflection (F_R-δ) diagram, which characterizes the behaviour of the material (Fig.2). The F_R-δ diagram shows two different types of behaviour of the beam specimens. The behaviour up to the first recorded macro-crack can be considered as a quasi-linear elastic (QLE) stage with reduced equivalent flexural rigidity ($B_{eq} = E_{fc} \, . \, I_{eq}$) affected by gradual increase of micro-cracking in tensile zone of beam due to effects of the bending moment.

In QLE stage, the bending moment resistance force at ultimate limit state (ULS) of the first macro-cracking ($F_{R,r}$) can be identified. From the corresponding bending moment the flexural tensile strength of PC or FC may be deduced by means of linear elastic theory.

The curve in the F_R-δ diagrams, generally, declines suddenly when the ULS of the first macro-cracking is trespassed. At this stage when the test when loading is controlled by deflection, the PC beam test specimens sustain a brittle failure (Fig.2a), while the FC beam test specimens show considerable deflection ductility (Fig.2b). The behaviour of FC beams at this stage changes significantly due to inelastic deformations in the tensile zone of the critical section with the macro-crack. The stress distribution in this section may be usually considered as quasi-plastic in the tensile zone and as quasi-elastic in the compressive zone (Fig.3).

In the critical section, fibres stiffen the cracked tensile zone of the beam test specimen and the so-called "equivalent residual tensile FC strength" $f_{t,eq,res}$ is actually only a theoretical uniform stress field under a given residual deflection δ_{res}. It replaces the tensile micro-forces of fibres acting in the tensile zone area of the critical section (Fig.3b).

a) REFERENCE PC BEAM TEST SPECIMEN



b) FRC BEAM TEST SPECIMEN
(ρ=0,5% OF SYNTHETIC FIBRES FORTA FERRO)

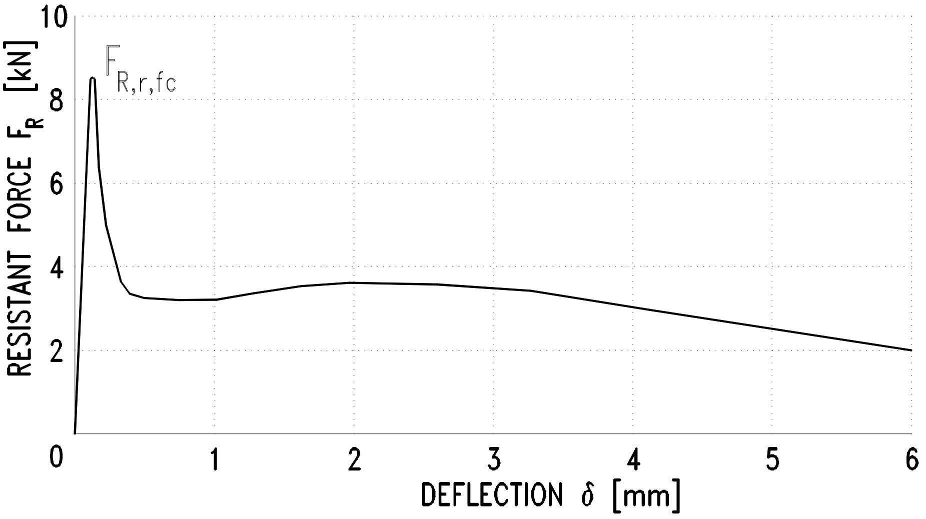


Fig.2 Diagrams F_R - δ for beam test specimens

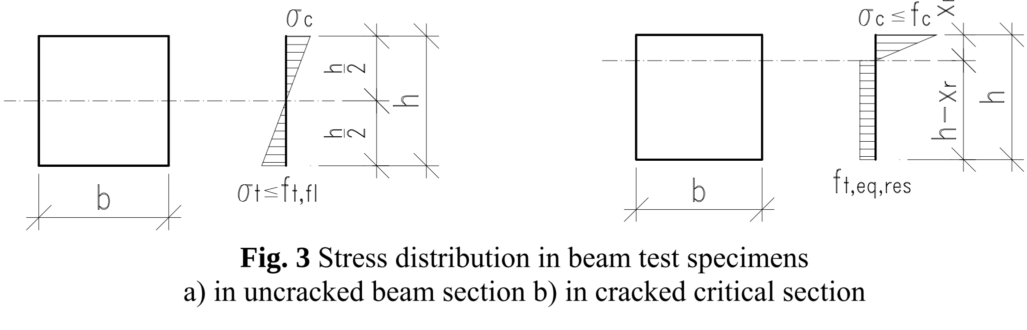

a) b)

Fig. 3 Stress distribution in beam test specimens
a) in uncracked beam section b) in cracked critical section

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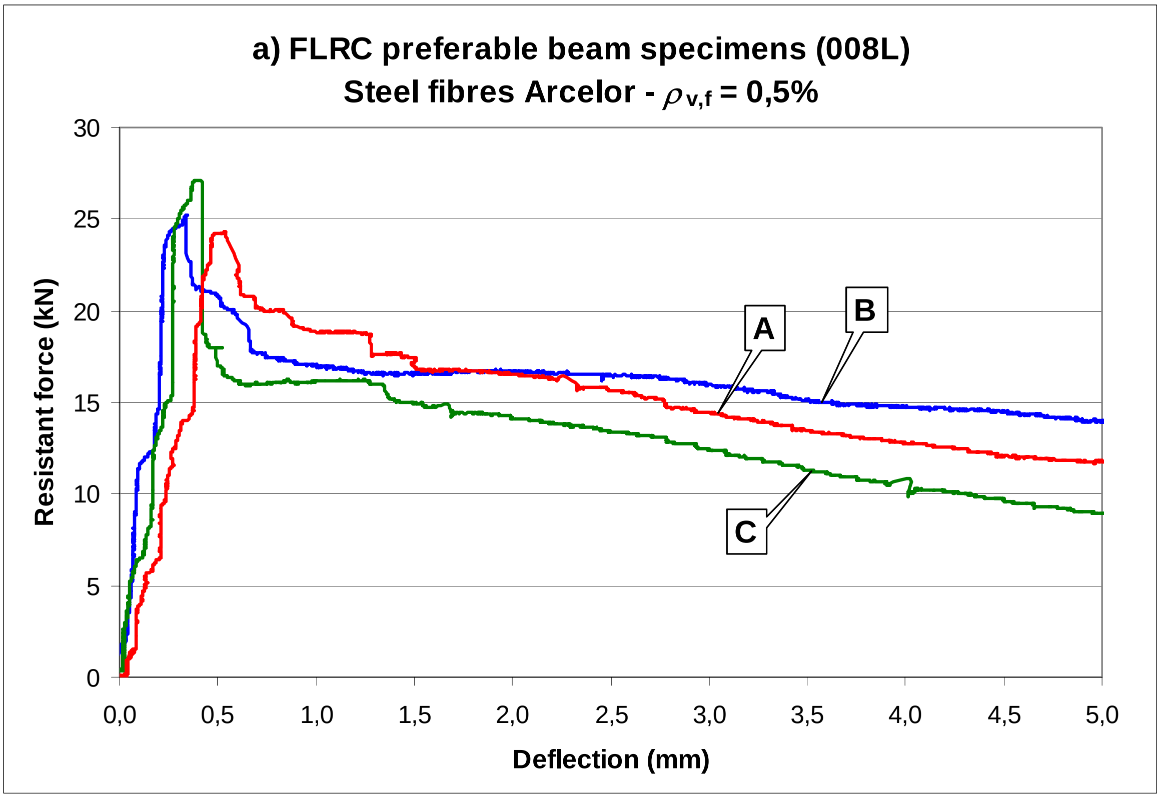

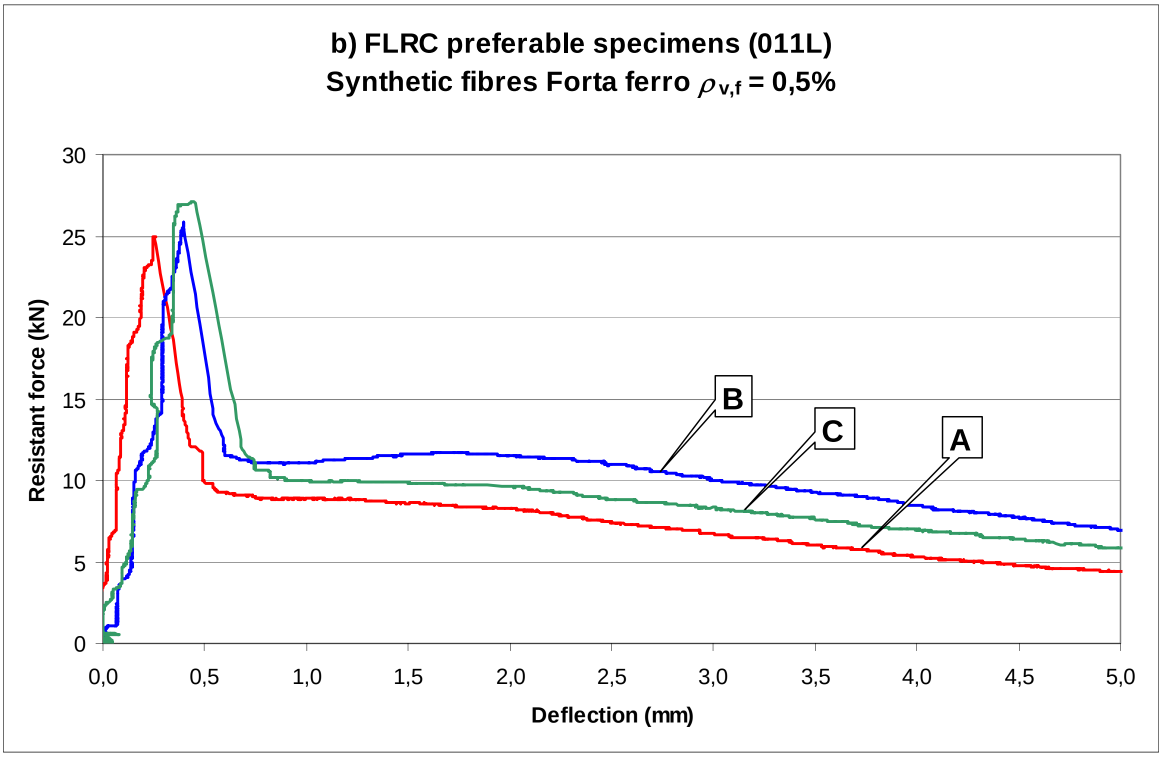

Fig.4 Comparison of diagrams F_R - δ of FC preferable beam test specimens with $\rho_{V,f}$ = 0,5% for different fibre materials: a) steel Arcelor fibres b) synthetic Forta Ferro fibres

After the macro–cracks are formed in the tensile zone of a critical section, the behaviour and resistance of beam test specimens is controlled by the influence of used fibres and quantity expressed by $\rho_{V,f}$. The quality of fibres (e.g. their strength), size (e.g. slenderness ratio, *l*/*d*) and form, which affects the bond between the fibres and cementitions matrix, ensure the anchorage efficiency of fibres, which is also essential

From the shape of the F_R -δ diagram after the ULS of macro-cracking, effectiveness of fibres in behaviour of FC beam test specimens can be considered. When the resistance force of FC (F_R) permanently declines in the F_R-δ diagram (Fig.4), the FC can be defined as a “Fibre lightly reinforced concrete” (FLRC). If the declining of the F_R-δ diagram stops at a cracked stage (Fig.2b) or starts again to grow but below the level of the ULS of macro-cracking ($F_{R,r,fc}$) (see Fig.5), the FC can be defined as a “Fibre reinforced concrete” (FRC). Only if the F_R-δ diagram declines just a little after the ULS of macro-cracking and next grows above the level of $F_{R,r,fc}$ (Fig.6), the FC may be defined as a “Fibre highly reinforced concrete” (FHRC). The post-cracking behaviour of the FHRC becomes that of the concrete reinforced with steel bars but the deflection ductility is smaller.

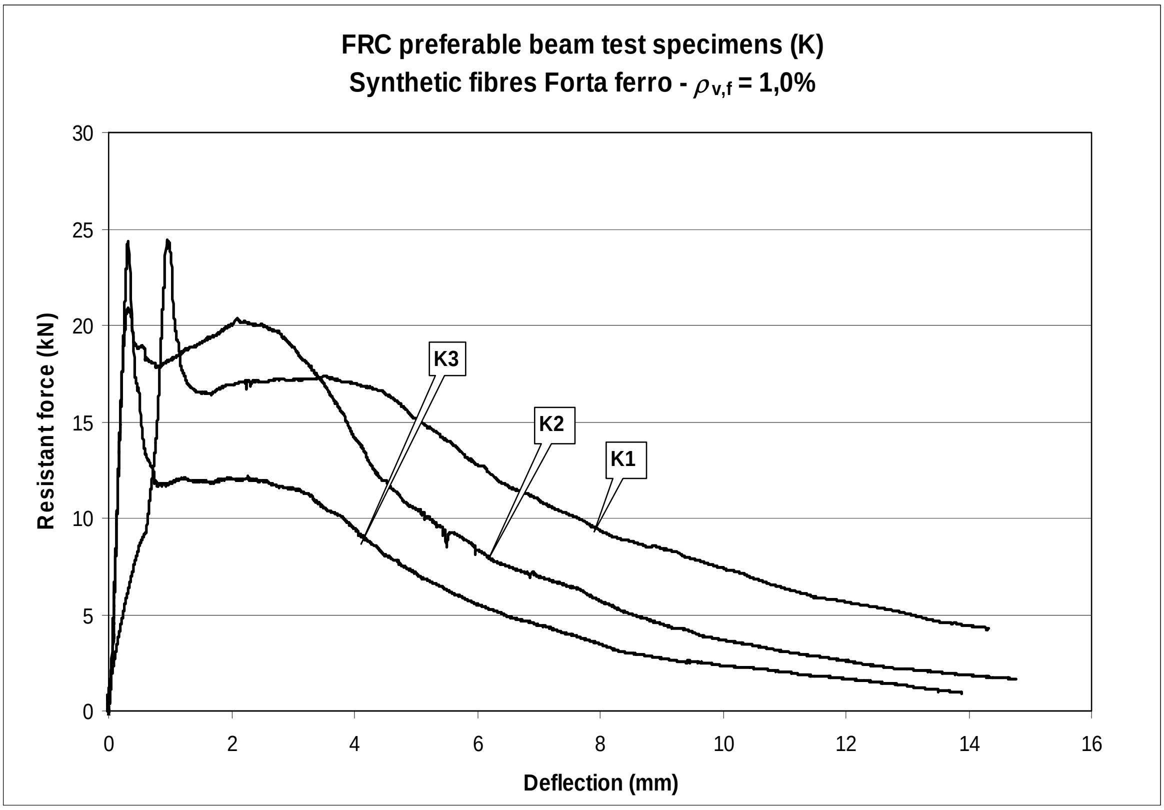

Fig.5 Diagrams F_R -δ for FC preferable beam test specimens with synthetic Forta Ferro fibres ($\rho_{V,f}$ = 1,0 %)

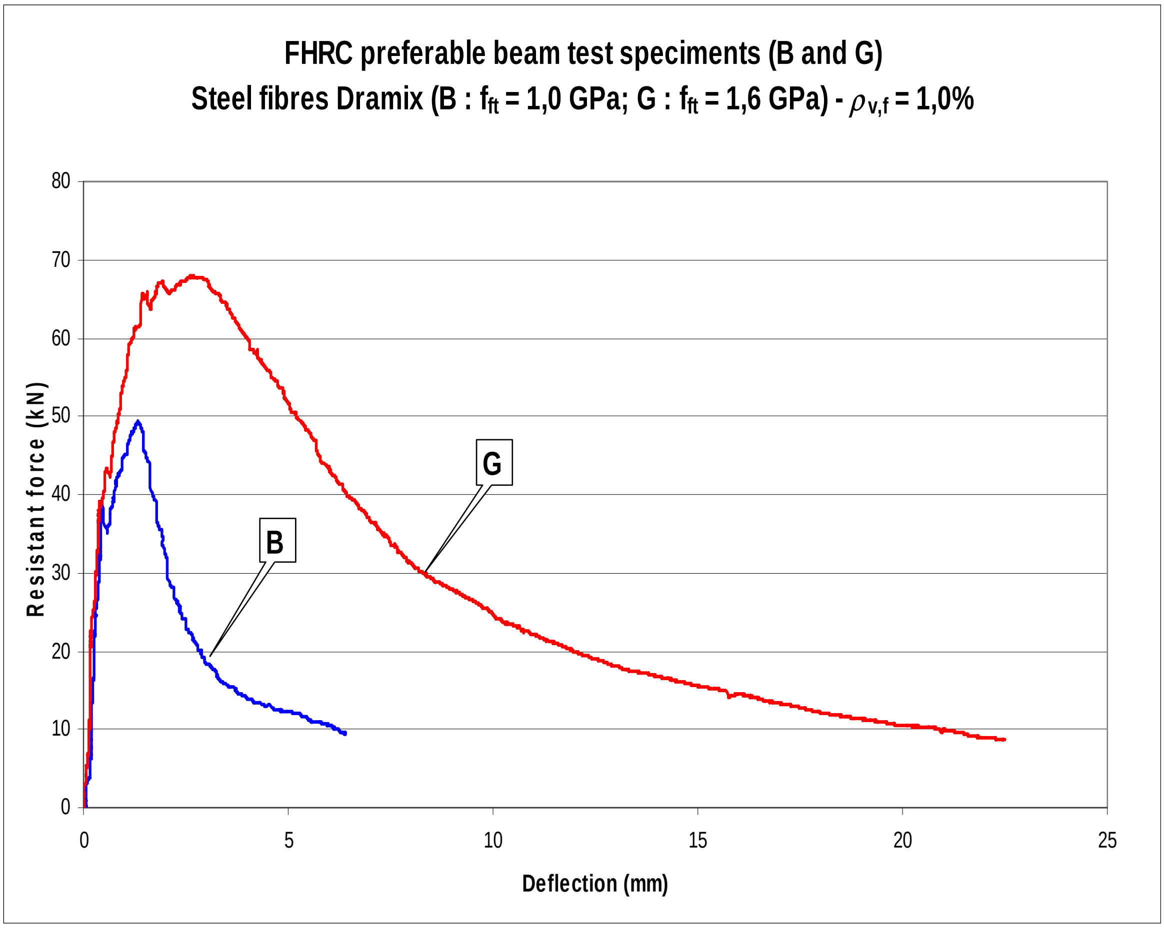

Fig.6 Comparison of diagrams F_R -δ for preferable beam test specimens (FHRC) with high strength steel Dramix fibres ($\rho_{V,f}$ = 1,0 %), tensile strength of fibres B: f_{ft} = 1000MPa, G: f_{ft} =1600MPa

The basic characteristics of FC beam test specimens can be deduced from the F_R -δ diagrams, especially at the post-cracking stage (Fig. 7), e.g.:

x_{res}	residual neutral axis depth after macro-cracking, or the ratio $\xi_{res} = x/h$
$f_{fc,t,fl}$	flexural tensile FC strength at ULS of macro-cracking
$f_{fc,t,eq,res}$	residual equivalent tensile FC strength under a given residual deflection after ULS of macro-cracking
$\varepsilon_{fc,t,qel,r}$	quasi-linear elastic tensile peak strain in the FC critical section at ULS of macro-cracking
$\varepsilon_{fc,t,tot}$	total tensile peak strain in the FC critical section after ULS of macro-cracking
w_{res}	residual crack width after FC critical section after ULS of macro-cracking
$l_{w,res}$	residual crack length after FC critical section after ULS of macro-cracking
$\lambda_{w,res}$	the ratio $\lambda_{w,res} = l_{w,res} / h$

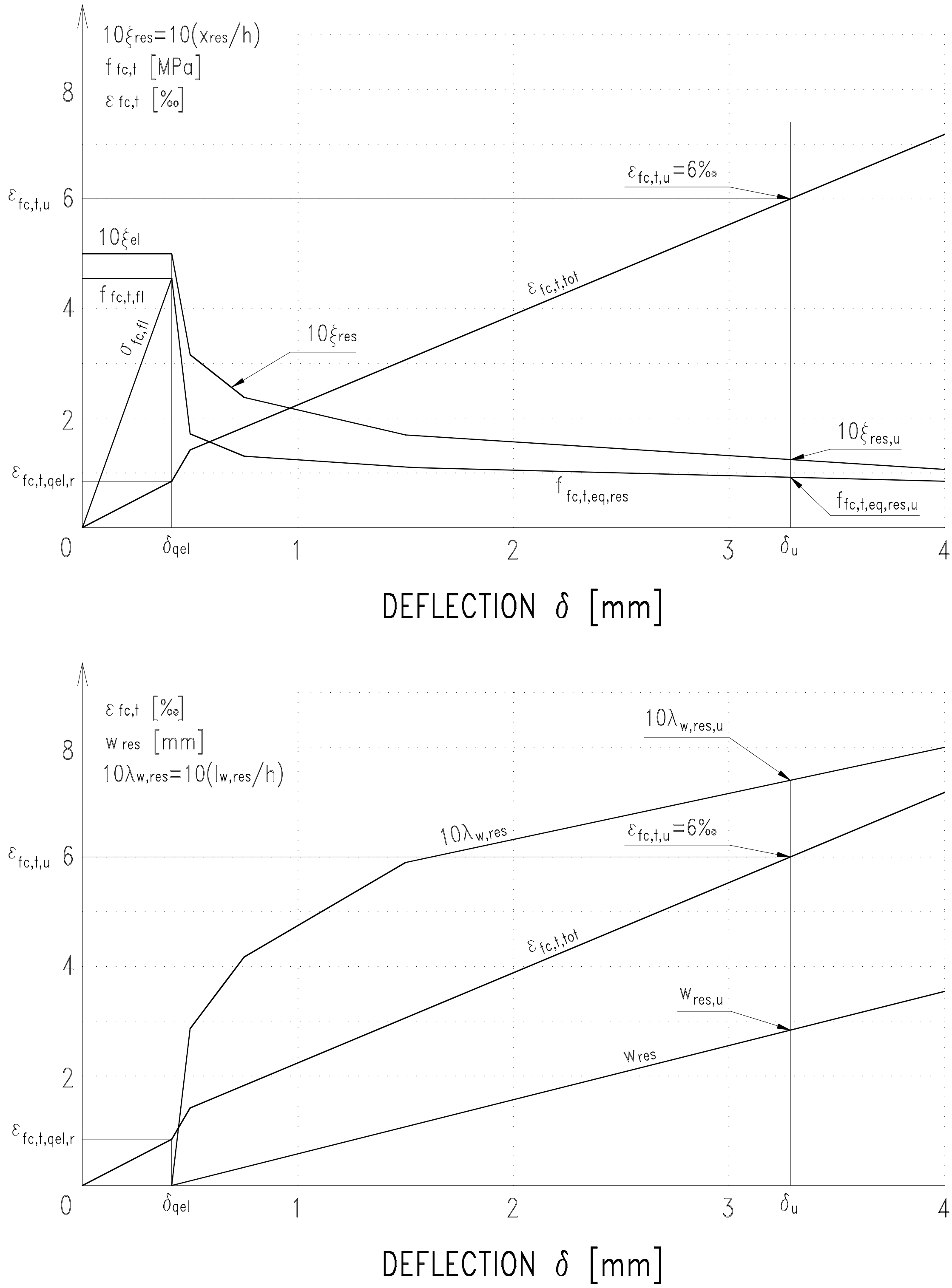

Fig.7 Basic characteristics of FLRC preferable beam specimens deduced from diagram F_R - δ
(the beam specimens 008L – see Fig.4a)

3 RFC with steel bar reinforcement

The behaviour of such a composite structural material should be tested on beams with higher slenderness than that of FC beams. A preferable beam test specimen shown in Fig.8 with slenderness $L/h = 10$ subjected to bending by controlled deflection may be considered exhibiting flexural behaviour similar to RFC beams. Shear failure is less probable for the shear stress slenderness $\lambda_v = M/(Vh) = 4.3$ of beam test specimens.

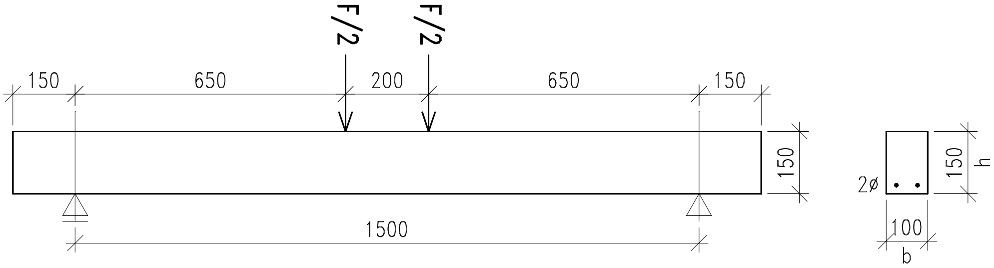

Fig.8 Setup of the preferable beam test specimen with L /h = 10, subjected to bending moment

The F_R-δ diagram for a RFC beam test specimen shows three different types of behaviour in comparison to RC beams. Since the behaviour of RFC beams is controlled by reinforcing steel strains until the yield point is achieved, the behaviour of resistance and deformation shall be very similar in the uncracked and cracked stage of RFC and RC beams. Therefore, the behaviour of RFC and RC beams before the steel yield stress of reinforcing bars has been reached can be considered as quasi-linear elastic with reduced flexural rigidity $B_{rs} = E_{fc} . I_{rs}$, which is affected by gradual increase of macro-cracking in the tensile zone of beams due to bending moment and by RFC with help of quasi-plastic behaviour of FC in the tensile zone. This behaviour is typical for SLS of RFC and RC beams. The effect of fibres is most significant in the tensile zone of beam test specimens after macro-cracking.

The differences of RFC and RC behaviour are greater only at the stage when the steel bars are yielding. The effect of fibres helps the plasticity performance of steel bars and it FC, not only in the tensile zone but also in the compressive zone at ULS (Fig.9). At ULS, also the deflection ductility can be affected by fibres (Fig.10) due to ultimate FC strain in tension $\varepsilon_{fc,t,u}$ (Fig.7). The deflection ductility of beam test specimens can be affected even by ductility class of reinforcing steel bars. The effect of fibres grows with increasing of strength of fibres f_{ft} and decreases with increasing of value of longitudinal reinforcement ratio $\rho_s = A_s/(bd)$ (Fig.11).

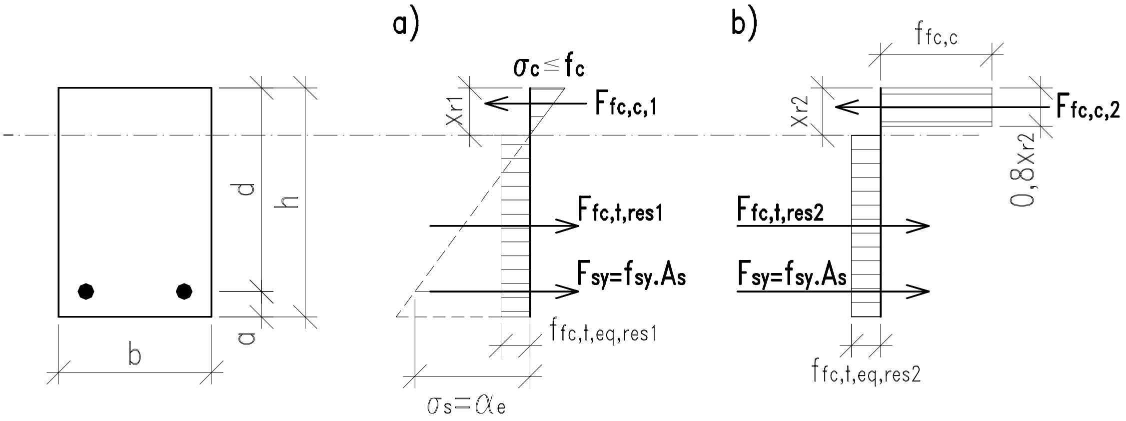

Fig.9 Idealization of stress distribution in RFC beam test specimen
a) SLS – quasi-linear behaviour b) ULS – quasi-plastic behaviour

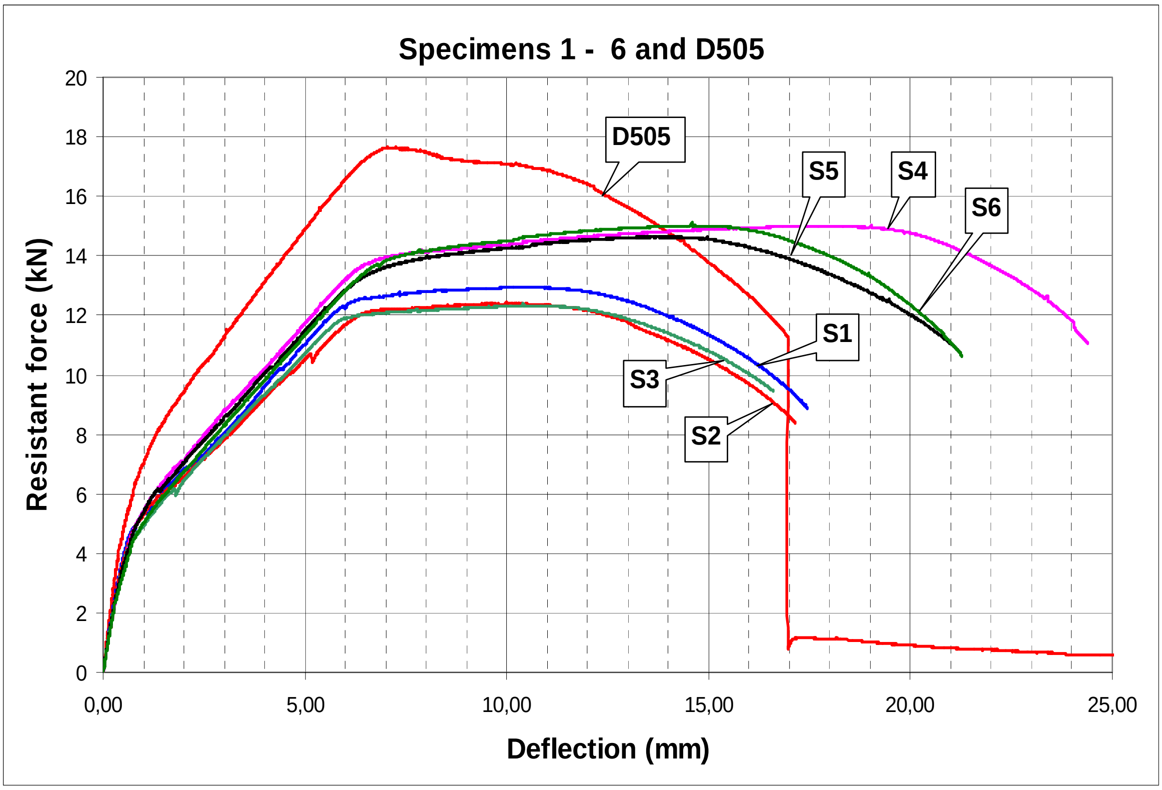

Fig. 10 F_R -δ diagrams for preferable beam test specimens with L / h =10
with reinforcing steel bars (f_{yk} = 490 MPa, ductility class A, ρ_s = 0,45%)
a) RC without fibres $\rho_{V,f}$ = 0 - (specimens 1, 2, 3)
b) RFC with synthetic Forta Ferro fibres, $\rho_{V,f}$= 1,0% - (specimens 4, 5, 6)
c) RFC with steel Dramix fibres f_{yt} = 1000 MPa, $\rho_{V,f}$= 1,0% - (specimen D505)

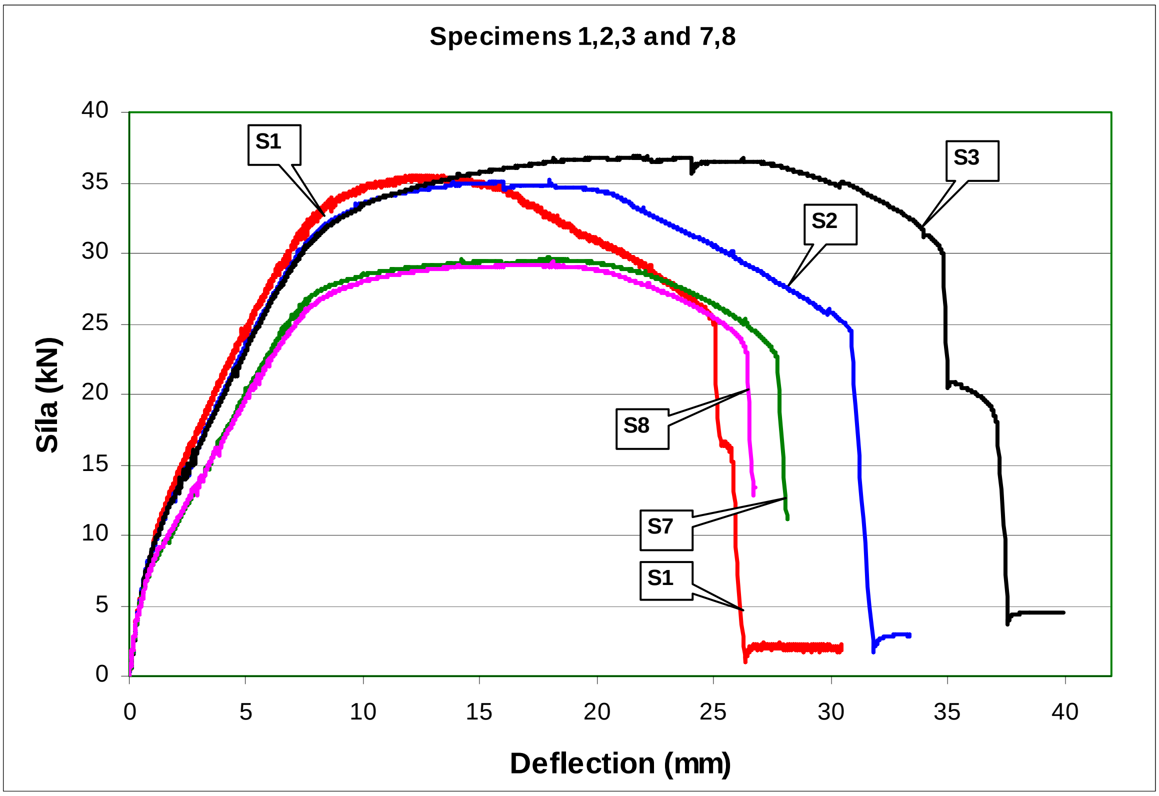

Fig.11 F_R -δ diagrams for preferable beam test specimens with L / h =10
with reinforcing steel bars (f_{yk} = 490 MPa, ductility class A, ρ_s = 1,0%)
a) RC without fibres $\rho_{V,f}$ = 0 - (specimens 7,8)
b) RFC with steel Dramix fibres f_{yt} = 1000 MPa, $\rho_{V,f}$= 1,0% - (specimen 1,2)
c) RFC with steel Dramix fibres f_{yt} = 1600 MPa, $\rho_{V,f}$= 1,0% - (specimen 3)

4 Conclusions

The typical behaviour of FC and RFC beams should be expressed in overall analysis of structure model compatible with the design model of PC and RC structures at ULS and SLS.

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References

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