ENVIRONMENTALLY FRIENDLY CONCRETE USING RESIDUES OF WOOD

BÓDI István[1], KORIS Kálmán [2]

Abstract

In this study, a calculation method is presented for wood fibre reinforced concrete. This combined material shares many favourable characteristics, such as small crack width values, great ductility and durability. However, the calculations show that the load-displacement behaviour deviates from conventional timber and reinforced concrete structures. By producing wood fibre reinforced concrete, an environmental-friendly structure has presented itself that has several advantageous features.

Keywords: durability, environmental-friendly, wood-concrete composite, wood shavings, pine needles

1. Introduction

An environmentally friendly and very economical possibility for using wood shavings or pine needles is to create wood fibre reinforced concrete, when these materials are mixed into the concrete uniformly, during the course of pouring. In this study, these combined materials will be analyzed from a different point of view.

Firstly, it will be shown what the load-displacement function looks like, and how the stress-strain relationship of the components influences this diagram. After that, the influence of the ratio of the components will be presented and the direction of the wood fibres will be considered here as well. Because of the small size of the wood fibres, the failure mode of these reinforcing materials is not obvious. However, determining the equilibrium condition of fibre pull-out for wood fibre, limitations can be set for the geometrical data, in order to avoid pull-out failure. On the other hand, the small size of the wood fibre is very favourable because of the several advantages, for example the small crack width values of this structure.

Due to the strong analogy to steel fibre reinforced concrete, a comparison is also presented in this study between wood fibre reinforced concrete and steel fibre reinforced concrete.

2. The effect of stress-strain relationships on load-displacement functions

Let us analyze the bending behaviour of an arbitrary rectangular cross-section of the wood fibre reinforced concrete. The changes of the stress distribution as a function of the

[1] BÓDI István, 1111 Budapest, Műegyetem rkp. 3, Hungary, +36–1–4631751, bodi@vbt.bme.hu

[2] KORIS Kálmán, 1111 Budapest, Műegyetem rkp. 3, Hungary, +36–1–4631751, koris@vbt.bme.hu

increasing curvature can be followed in the concrete and the fibres as well. Whilst the behaviour of the concrete and the fibres are elastic, the position of the neutral axis does not change. When the tensile stresses in the concrete exceed the non-linear section, the position of the neutral axis moves towards to the top. This movement speeds up gradually when the concrete cracks. Due to the movement of the neutral axis, greater strain keeps springing in the lower fibres. The cross section has the maximum moment when the lower fibres are just at the point of tearing, or pull-out. By increasing the curvature after the failure of the lower fibres, more and more grain fails from the bottom to the top. The moment-curvature relationship is the function of the stress-strain relationship that is assumed, of course. The moment-curvature functions is plotted for different cases (a, b, and c) in Fig. 1.

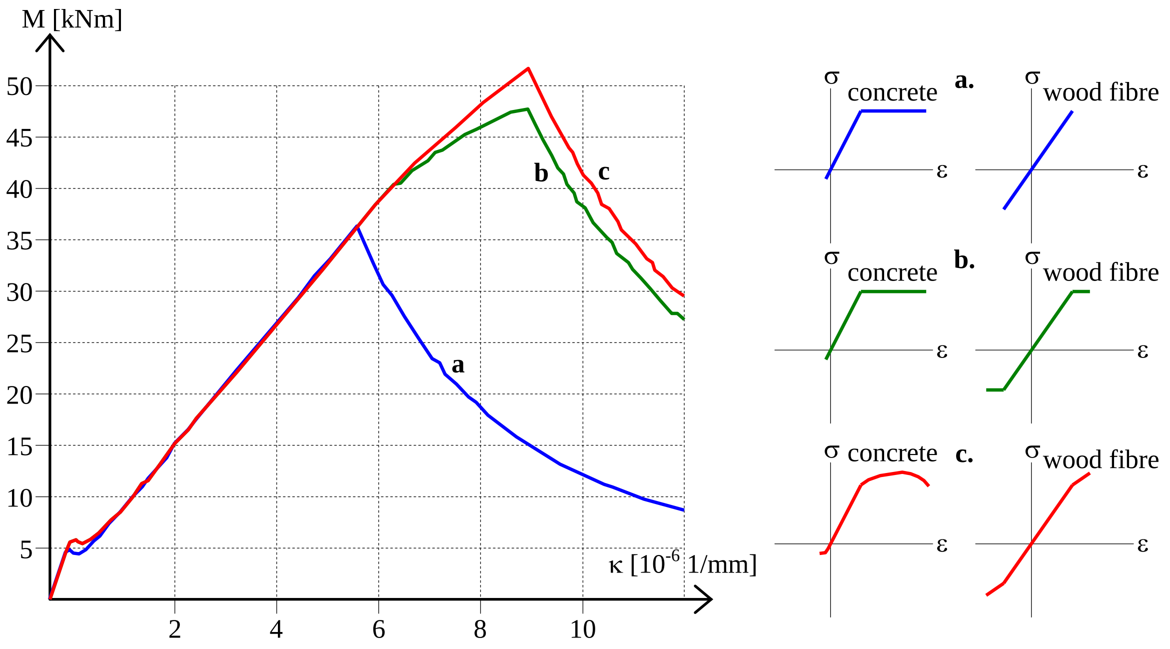

Fig. 1: Moment-curvature relationship of wood fibre reinforced concrete in case of different stress-strain relationships

3. The effect of the composition on the load-displacement functions

Important data is the ratio of the wood fibre to the concrete as well. The result plotted in Fig. 1 concerned a composition with 30% wood fibre content. Let us analyze how the ratio of the wood fibre affects the moment-curvature relationship. The results can be seen in Fig. 2.

The moment-curvature relationships presented in Fig. 2 are regarded as valid results, if the analysed cross-section is a part of a structure where the wood fibres are perpendicular to the cross-section. So the fibres are placed similarly to the axial reinforcement in the reinforced concrete. If the structure is produced in such a way that the wood fibres are mixed at random into the concrete, not all of the fibres will be in a perpendicular position to the cross-section. The non-axial fibres can be considered by taking the axial component of the force of these fibres. This procedure corresponds to such a calculation where just a part of the fibres are considered, but the directions of these fibres are axial. The quotient of the equivalent fibre percentage and the real fibre percentage is named the direction factor (I_t).

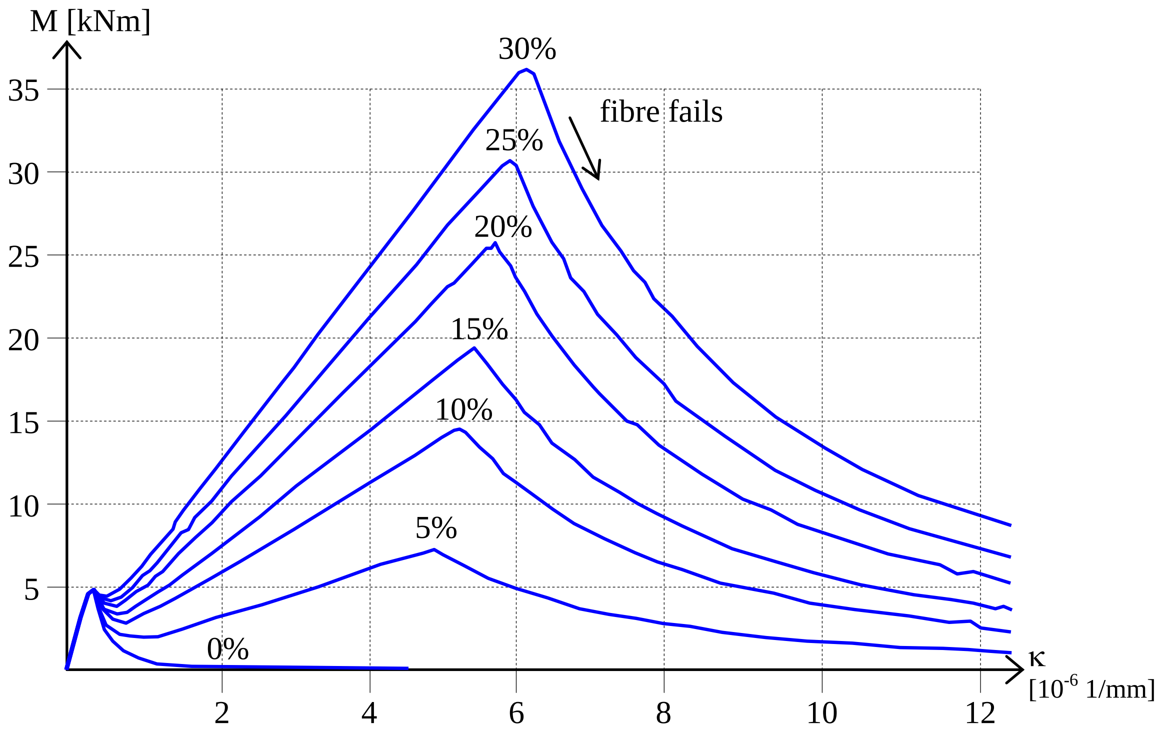

Fig. 2: Moment-curvature relationship in case of different fibre ratios

Based on empirical data, it can be assumed that the value of the direction factor is $I_t \approx 0.5$ in the case of appropriate pouring. The modified moment-curvature relationship, plotted in Fig. 3, considers different direction factors.

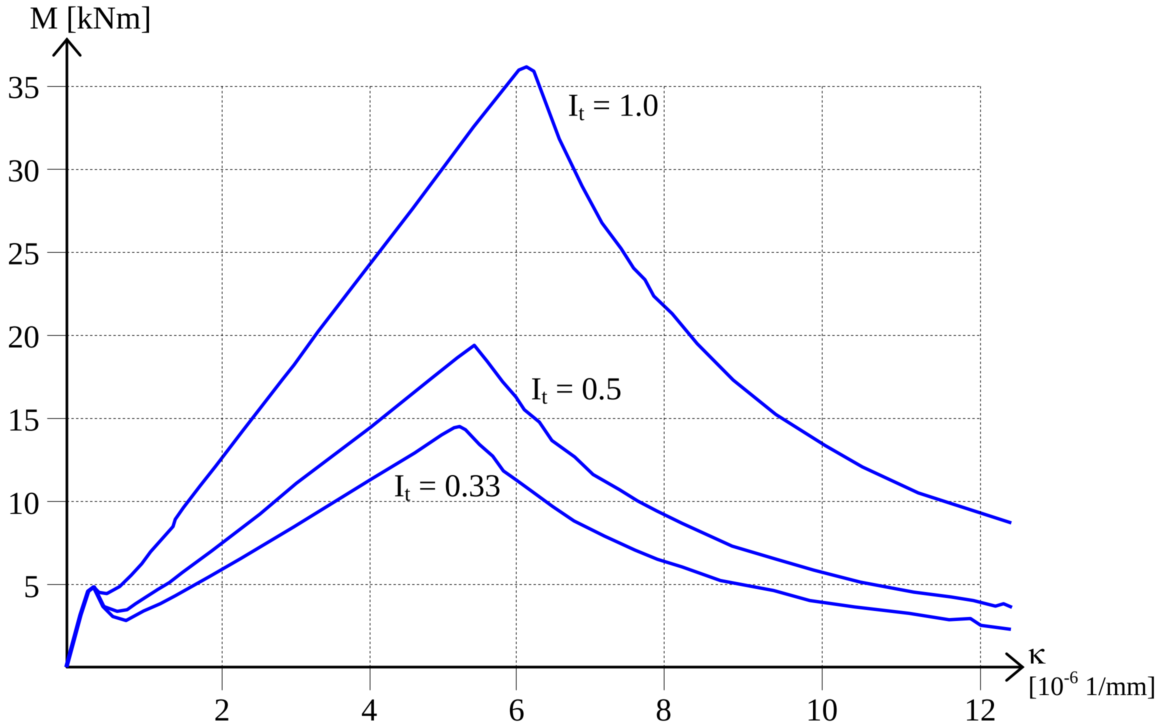

Fig. 3: Moment-curvature relationship in case of different direction factors

4. Pull-out analysis of the wood fibres

The points of maximum bending moments in the previous diagram are reached when the lower fibres are just at the point of rupture. At this level of bending moment the stress presented in the lower fibres is exactly equal to the tensile strength of the wood fibre. So, the pull-out analysis is an important question, because if the pull-out occurs earlier than the rupture, since the lower fibres fail before reaching the tensile strength. In order to analyze the possible pull-out failure, let us take a look at the equation of the equilibrium of a lower fibre:

$$A \cdot \sigma_w = d^2 \cdot \frac{\pi}{4} \cdot \sigma_w = \frac{d \cdot \pi \cdot l}{2} \cdot R_{adh} \tag{1}$$

where: – d is the substitutive diameter of the wood fibre,
– A is the section area of one fibre,
– σ_w is the tensile stress yielding in the wood fibres,
– l is the anchorage length of the wood fibre,
– R_{adh} is the adhesive shear strength between the concrete and the wood fibre.

The left side of the equation contains the tensile force obtained for the wood fibre, however on the right hand side the anchoring force can be found. This anchoring force considers an I_t = 0.35÷0.5 direction factor and an adhesive stress distribution, which varies linearly. Let the adhesive shear strength be the same value as the tensile strength of the concrete. The ratio of the substitutive diameter of the fibre to its anchorage length can be expressed in the following form:

$$\frac{d}{l} = 2 \cdot \frac{R_{adh}}{\sigma_w} \tag{2}$$

It is assumed that the adhesive shear strength between the concrete and the wood fibre corresponds to the tensile strength of the concrete, so that there is no need to determine the moment-curvature relationship to get the critical value of d/l. Because the maximal moment is reached just before the failure of the lower fibres, the critical value of d/l can be calculated by substituting the tensile strength of the wood for σ_w. If the ratio of the substitutive diameter of the circular cross-sectional wood fibre to its anchorage length is greater than the two-times tensile strength of the wood, the lower fibres fail by pull-out.

5. Crack width analysis of the structure

Cracks in concrete beams (Fig. 4) reduce the bending stiffness of the structure, therefore it is important to determine the crack width of wood fibre reinforced elements. Eurocode 2 calculates the crack width values of the reinforced concrete structures by determining the difference of the strains between the concrete and reinforcement. According to this approach the crack width of wood fibre reinforced concrete can be expressed by the following approximate formula, where strain of the concrete is neglected:

$$w = \frac{\sigma_t}{E_t} \cdot s \tag{3}$$

where: – σ_t is the stress yielding in the lower fibres,
– E_t is the young modulus of the wood,
– s the distance between the cracks.

Fig. 4: Cracking of a pine needle reinforced concrete specimen subjected to bending

The distance between the cracks (*s*) can be calculated from the equation of equilibrium of the wood fibres. But here, the un-cracked state of stress compared to that of the cracked state, cannot be recognised. So σ_t stress in the lower wood fibre will be substituted with a stress which belongs to the actual curvature (κ). This procedure is only suitable for presenting the order of magnitude and the changing of the crack width value. The substituting tensile force (F_t) in the lower fibre:

$$F_t = \frac{d^2 \cdot \pi}{4} \cdot \sigma_{tr}(\kappa) - \frac{d^2 \cdot \pi}{4} \cdot \sigma_t(\kappa) + d \cdot \pi \cdot \frac{s(\kappa)}{2} \cdot \alpha \cdot f_{ct} \tag{4}$$

where: – d is the substitutive diameter of the wood fibre,
– σ_{tr} is the stress before the cracking of the concrete in the lower fibres,
– σ_t is the stress yielding in the lower wood fibre,
– α is the proportionality modulus.

The calculated bending moment – curvature and crack-width – curvature functions are presented in Fig. 5 below.

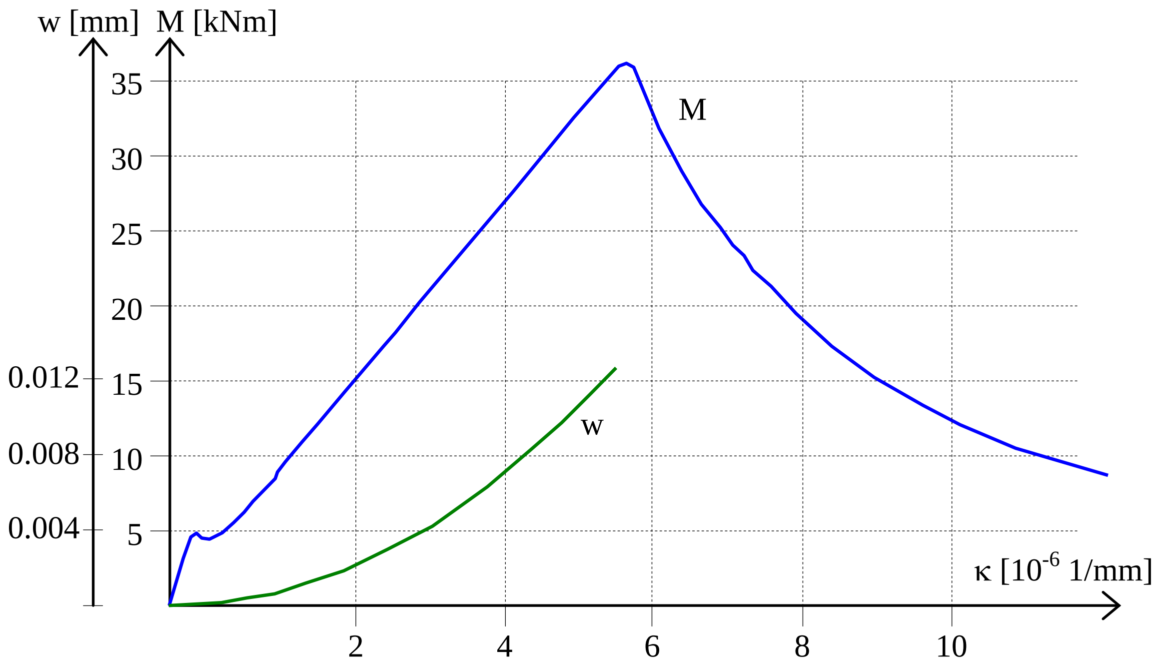

Fig. 5: Crack width values and the moment curvature relationship of wood fibre reinforced concrete

6. Experimental results

To analyse the behaviour of wood fibre reinforced concrete some compressive and three point bending tests were performed on pine needle reinforced concrete specimens (labelled with letter F). Concrete specimens without fibre reinforcement were also tested for the reason of comparison. All specimens were casted from grade C20/25 concrete, and the fibre content of F-marked specimens was 5 weight percent. For three point bending tests the span of the prism specimens was 120 mm. Some of the compressive test results are illustrated in Tab. 1, while bending test results are presented in Tab. 2.

Tab.1: Results of compressive test of pine needle reinforced concrete cube specimens

Nº of specimen	Size			Mass	Density		Failure load (F)	Area (A)	Compressive strength			
	b	h	L		Individual	Average			Measured (f_{cube}=F/A)	Mean value	Standard deviation	Char. value $f_{ck,70,cube}$ (p=5%)
	mm	mm	mm	kg	kg/m^3	kg/m^3	kN	mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2
4	70,7	70,7	70,7	0,787	2227	2218	178,0	4998,5	35,6	36,94	2,66	32,56
5	70,7	70,7	70,7	0,782	2213		200,0	4998,5	40,0			
6	70,7	70,7	70,7	0,782	2213		176,0	4998,5	35,2			
4F	70,7	70,7	70,7	0,772	2185	2190	119,0	4998,5	23,8	23,64	0,21	23,30
5F	70,7	70,7	70,7	0,772	2185		118,5	4998,5	23,7			
6F	70,7	70,7	70,7	0,778	2202		117,0	4998,5	23,4			

Tab.2: Results of bending test of pine needle reinforced concrete prism specimens

Nº of specimen	Size			Mass	Density		Failure load (F)	Section modulus (W)	Tensile strength			
	b	h	L		Individual	Average			Measured (f_t=M/W)	Mean value	Standard deviation	Char. value $f_{tk,test}$ (p=5%)
	mm	mm	mm	kg	kg/m^3	kg/m^3	kN	mm^3	N/mm^2	N/mm^2	N/mm^2	N/mm^2
1	40	40	165	0,581	2201	2201	1,7	10667	4,8	5,46	0,58	4,50
2	40	41	165	0,595	2199		2,2	11207	5,9			
3	40	40,5	165	0,589	2204		2,1	10935	5,6			
1F	40	41	160	0,554	2111	2111	1,7	11207	4,6	4,65	0,08	4,52
2F	40	40,5	160	0,552	2130		1,7	10935	4,7			
3F	41	40,5	160	0,556	2093		1,7	11208	4,6			

Because of the relatively low fibre content, the compressive strength of fibre reinforced cube specimens was smaller than the strength of control specimens (without fibre content). However, fibre reinforced specimens had much higher ultimate compressive strain, thus fibre reinforcement provided much higher ductility to the concrete as shown in Fig. 6. It is interesting that the standard deviation of concrete strength (both compressive and tensile strength) was lower in case of fibre reinforced specimens. The mean tensile strength of pine needle reinforced specimens was slightly lower than in case of the control specimens, however smaller standard deviation resulted in higher characteristic value.

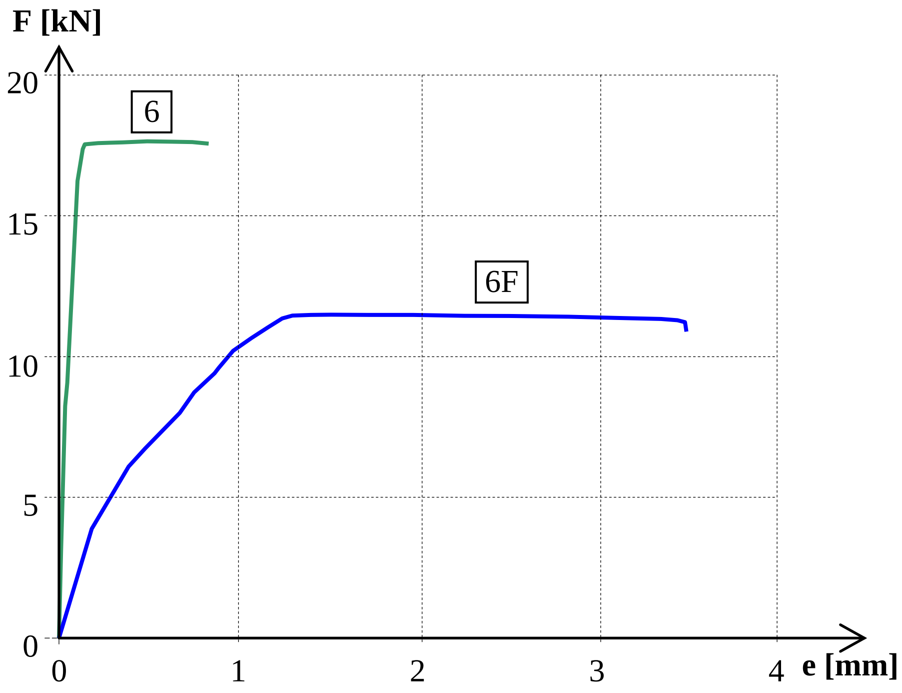

Fig. 6: Load-displacement curves of concrete cube specimens with and without fibre reinforcement

7. Comparison of wood fibre and steel fibre reinforced concrete

In spite of the similarity of the structural building up of steel fibre and wood fibre reinforced concrete, there are a lot of differences in their behaviour. The moment-curvature relationships of these above-mentioned composites are plotted in Fig. 7. The 30% fibre content is normal in the case of wood fibre reinforced concrete, but in the case of steel fibre reinforced concrete, it is an extraordinarily high quantity. This is how the capacity in Fig. 7 can be explained. An interesting difference is the constant moment section of the steel fibre reinforced concrete as well, which is owing to the plastic behaviour of the steel.

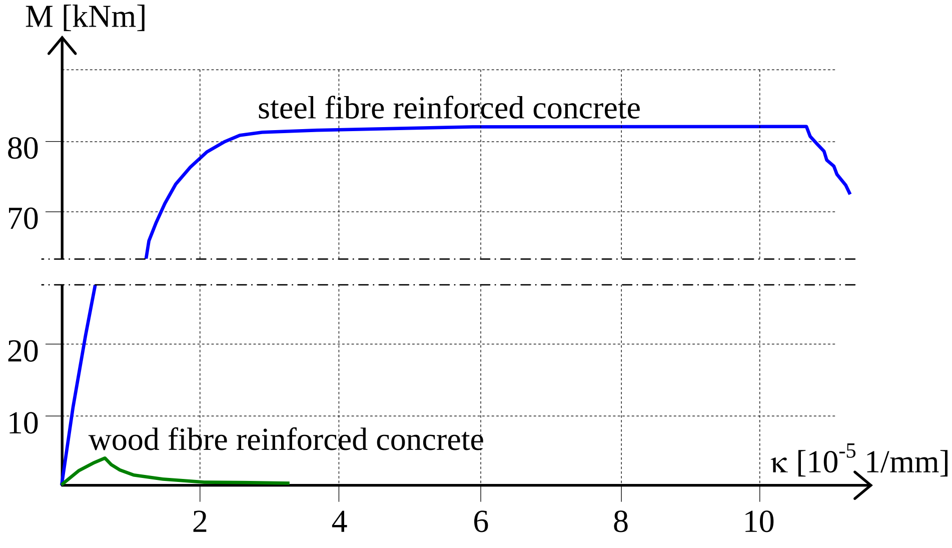

Fig. 7: Comparison of the moment-curvature relationships of wood grain and steel fibre reinforced concrete

8. Conclusions

Completed tests with fibre reinforced concrete show that the steel fibre placed in the concrete increase the tenacity and decrease the crack width of the concrete structure. Wood shaving or pine needle reinforced concrete has also many similar characteristics. Favourable crack width values also can be observed here, as well as great ductility. The main difference is that in this case, wood shavings or pine needles are included in the concrete instead of steel fibres. However, the calculations which consider the stress-strain relationship of the wood and the concrete show that the loading-displacement function deviates from those of conventional timber and reinforced concrete structures. A substantial difference can be experienced after the failure, because when the carrying capacity exceeds the maximum, it starts to decrease gradually but not as quickly as in the above-mentioned structures. By producing wood fibre reinforced concrete, an environmental-friendly structure has presented itself, which has several favourable characteristics like reduced self weight, small crack width values, great ductility and durability.

References

[1] BALÁZS L. Gy. (Ed.) *Fibre reinforced concrete – from the research till the application (in Hungarian).* Conference Proceedings, Hungarian Group of fib, Budapest 1999. ISBN 963-420-589-5.

[2] ACI Committee 544. *State-of-the-Art Report on Fiber Reinforced Concrete*. ACI Committee Report 1986.

[3] DULÁCSKA E. *Design theory of steel fibre reinforced concrete and reinforced concrete (in Hungarian).* Proceedings of the Conference „Fibre reinforced concrete – from the research till the application“, Hungarian Group of fib, Budapest 1999. ISBN 963-420-589-5.

[4] ASTM C 1018-89. *Standard Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)*. 1989

[5] JSCE-SF4. *Method of tests for flexural strength and flexural toughness of steel fibre reinforce concrete*. 1984.

[6] JSCE-SF5. *Method of tests for compressive strength and compressive toughness of steel fibre reinforce concrete*. 1984.