COMBINED REINFORCEMENT – EFFECT OF STEEL FIBRES IN A CRACK WIDTH DESIGN

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Abstract:

In the past, steel fibres were hardly being used in combination with traditional reinforcement. Nowadays combined reinforcement is getting a growing importance especially in Western Europe. This paper discusses the crack propagation with special regards to the crack width design in which the post crack strength of steel fibre concrete can be taken into account. Moreover some of numerous projects which have been carried out since then will be presented.

Keywords: Steel fibre, Fibre reinforced concrete, Combined reinforcement, Cracking, Tensile strength, Post crack strength,

1 Introduction

Concrete has a low tensile strength and tensile strain capacity and cracking is initiated at a tensile strain of about 0,1mm/m. Consequently cracks are almost not avoidable and reinforcement is needed to control the behaviour of cracking respectively to limit cracks to a certain width so that they are neither harmful to the structure nor to its durability and serviceability. Especially the actual standards for reinforced concrete like EC2 point out durability and serviceability aspects. So far traditional reinforcement was used to do this job, as for traditionally reinforced concrete rules and design formula for crack width control are state of the art. Steel fibres are well known for their ability to transfer stresses already at very small crack openings, so that ductility and post crack strength will be provided to the concrete. Hence Steel fibre reinforced concrete is widely used for applications like industrial floors, foundation slabs, tunnelling or precast elements. Relating to these applications, SFRC is supposed to be a well established building material and a meaningful alternative to plain or reinforced concrete. But much more is feasible with SFRC especially when one of the major benefits of steel fibre concrete is considered: The very positive effect on crack formation and crack development.

2 Cracking process

Cracking may be caused by external applied forces, imposed deformations, internal or external thermal stresses, shrinkage, or by a combination of these. When cracking is caused by an external applied load the crack width, if sufficient amount of reinforcement is added, depends on the applied force. If cracking is caused by restraint, an internal stress or an imposed deformation the force in the structure is in dependency of the actual stiffness of

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the structure. The most important parameter is the tensile strength of the concrete. As this is a time-dependant material regarding to its strength it is important to figure out when cracks are most likely to be due. In some cases such as the dissipation of the heat of hydration it is sufficient to reduce the 28-day tensile strength by 50% which has a high influence to the required reinforcement. When the time of cracking is not supposed to occur before 28 days which can be the case for a fully restrained structure under thermal stresses, the tensile strength of hardened concrete has to be taken into account. But certainly this will result in kind of heavy required reinforcement. Reduced bond and problems with placing and compacting the concrete might be the consequence. Finally it is up to the engineer to determine the right load case and the supposed cracking time to establish a reasonable crack width design.

3 Effect of Steel fibres on reinforced concrete

It is well known that steel fibres provide post crack strength to the concrete. After cracking, the fibres bridge the cracks and transfer loads from one side to the other. Usually steel fibres bridge a crack at a non perpendicular angle. Therefore the fibre will be bent already at small crack widths. Due to the locally increased friction, compressive stresses parallel to the crack surface are induced. As a consequence, the associated tensile stresses perpendicular to the crack can lead to a secondary crack. They can be compared with those cracks in reinforced concrete which can be found in the zone directly around rebars. With steel fibre concrete, they can be observed over the whole cracked section. Subsequently cracks become more curved and the resistance to intrude substances, especially liquids into concrete is significantly increased.

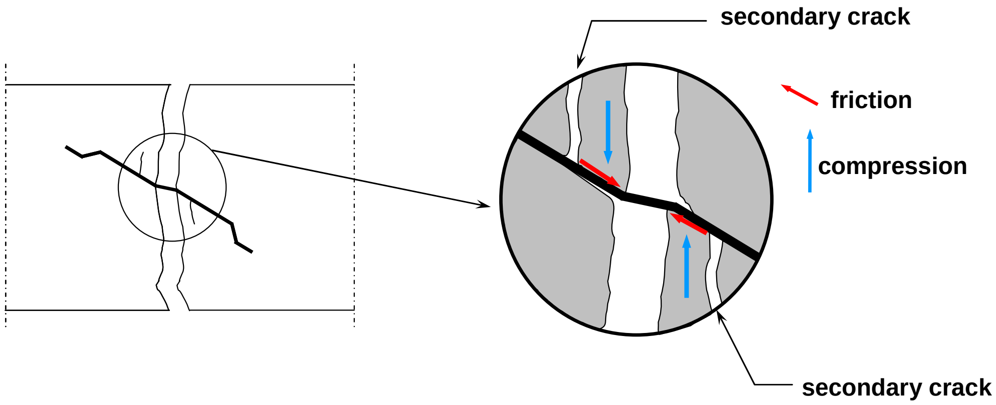

Fig. 1 Crack propagation due to steel fibres

However, for normal fibre dosages the post crack strength is always lower than the first crack strength. Therefore steel fibre reinforced concrete can be considered as a subcritical reinforcement. Only with high performing fibres at high dosages (e.g. 50kg/m³ Dramix® RC-80/60-BN) the ultimate load derived from a bending test is higher for the cracked than for the uncracked section. On the contrary the post crack tensile strength will still be lower. Due to the material behaviour of steel fibre reinforced concrete it is not possible to calculate a crack width without adding additional reinforcement - except in those cases where a compressive zone is permanently present (pre-stressed structures or those with compressive loads, statically indeterminate structures without axial restraint, …). Steel fibres cannot change the crack width requirement of a structural application, but what steel fibres can do is taking up a meaningful part of the force being released when the concrete is cracking. This happens by providing the so called post crack strength of steel fibre concrete. Assuming a concrete tensile strength of e.g. 3,0 N/mm² while providing an equivalent tensile strength (post crack strength) of 1,0 N/mm² when using steel fibres, only 2/3 of the full crack load has to be considered for the design. This has a strong effect on the required reinforcement. As crack width is a function of concrete tensile strength, known formula in e.g. EC2 or other standards can be adopted by subtracting residual or equivalent tensile strength from effective concrete tensile strength f_{ct}. It is important to use this two values together with the same concrete age. Meanwhile a number of guidelines and recommendations with modified formulas to calculate the released energy are available to design the crack width with combined reinforcement. In order to reach an effect as high as possible and to decrease the traditional reinforcement in a significant way, it is pretty important to make use of high performing steel fibres. The CE certification for steel fibres which is mandatory in Europe gives a first estimation of the performance of each fibre type. A certain performance obtained in a 3-point bending test has to be reached with a defined dosage of fibres. For example the high performing steel fibre type “Dramix® RC-80/60-BN” has already met this requirement with 10 kg/m³. A dosage of this fibre type between 20 kg/m³ and 30 kg/m³ for example will decrease the required amount of traditional reinforcement meaningful in a crack width design.

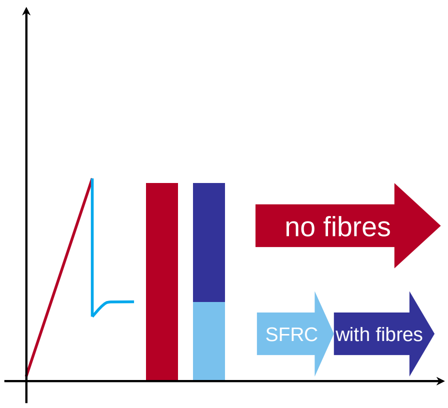

Fig. 2 Released fracture energy with and without the effect of fibres

As a rule of thumb, the required amount of reinforcement can be reduced up to 50% when using high performing steel fibres. This allows for larger distances between rebars and/or smaller diameters while keeping crack width at the same level. Installation process will become less complicated, more accurate and faster. Pouring and compacting concrete becomes easier and better results are likely. In many cases, rebars can be replaced by welded mesh so that even more time is saved and other building methods can be applied. Examples will be given in the following chapter. In any case, steel fibres even reinforce the concrete cover - which is definitely not the case for reinforced concrete alone. Furthermore, the whole section benefits from steel fibres, even outside the effective zone in which the reinforcement takes effect.

4 Practical experiences

Meanwhile a lot of experience with combined reinforcement to control the crack width was gained. A variety of projects has been carried out in countries all over the world. A few examples shall point out the benefits which were achieved by using this alternative. An elaborated description of these and further projects is given by G.Vitt in [7]

4.1 Industrial Floor Repair

The surface of an existing saw cut floor was damaged after some years in use (industrial park in Ismaning, Germany). A layer of 8cm was milled and replaced by 8cm new floor with combined reinforcement. The new layer was separated from the old slab by a double layer of plastic sheet. The joint distance was 27m x 30m, the total size 3,400m². Saw cuts could be avoided which means less maintenance work. The new joint layout, using special joint profiles with edge protection, could be aligned with the current needs and did not need to match with the old saw cuts. A mesh with steel section 2.95 cm²/m in both directions was combined with 35 kg/m³ Dramix® RC-65/60-BN (end-hooked, length 60mm, diameter 0,9mm). Construction was simplified and sped up due to the use of a light mesh. A concrete pump was not needed as the truck mixers could drive directly to the pouring point. Placing of the light mesh could be done simultaneously with the pouring when needed. The calculated crack width of 0.2mm was not exceeded.

Fig. 3 Repair layer. The mesh could be placed parallel to pouring of the concrete

4.2 Industrial Floor as Secondary Barrier

An industrial floor had to be designed as a secondary barrier against hazardous substances (production facility, Waldenburg, Germany 2003). The calculated crack width needed to be limited to 0.1mm in this case, following the regulations of [2]. The 20cm thick slab was poured on a double layer of plastic sheets to reduce the stresses due to restraint deformation. Joint distances were about 30m x 30m. A top mesh Q513 (steel section 5.13 cm²/m in both directions) was combined with 30kg/m³ Dramix® RC-80/60-BN (end-hooked, length 60mm, diameter 0,75mm). The total size of the project was 15,000m². Instead of a double layer reinforcement consisting of a large number of single rebars, a strong mesh could be combined with high performing steel fibres. The time for installing the reinforcement was significantly reduced as the reinforcement could be installed parallel to casting. Hence the use of a concrete pump could be passed up.

Fig. 4 Secondary barrier / Laser screed compacting and levelling concrete

4.3 Shotcrete Shell

Combined reinforcement was used in this example for a thin shell structure in the oceanographic park Valencia (Spain). 50kg/m³ Dramix® RC-80/35-BN (end-hooked, length 35mm, diameter 0,45mm) and a single mesh Ø8-15cm were applied. Due to the curvature and the limited shell thickness of 6cm to 12cm it would have been very difficult to install a complicated traditional reinforcement in an accurate and safe way. A maximum diameter of 8mm rebar was preferred due to the demanded concrete cover. Hence the traditional reinforcement had to be placed close to the neutral axis of the section why the post crack strength of the steel fibre reinforced concrete was also applied for the ultimate limit state. Concrete was applied by shotcrete technology. With the chosen combination, both serviceability and ultimate limit state could be designed.

Fig. 5 The final shell: Maybe the most beautiful example of combined reinforcement

5 Conclusions

Steel fibre reinforced concrete has proven over the years to be a reliable construction material. After years of research and experience new possibilities in regards to combined reinforcement are feasible. Particularly the effectiveness for crack control has proven outstanding well. In the case of combined reinforcement, durability, serviceability and construction time may be improved in one pass. Significant savings of maintenance costs may be achieved in addition. It is possible to introduce the effect of steel fibre reinforcement in models for force or restraint introduced cracking. Meanwhile a number of guidelines and recommendations are available to design the crack width with combined reinforcement. Amongst others Rilem TC 162-TDF [1], the German Guideline for Steel Fibre Concrete [3], the Austrian Guideline for Fibre Concrete [4], the DBV-Recommendation for Steel Fibre Concrete [5] and can be listed in this context. The use of combined reinforcement will certainly increase in fields of application which are currently dominated by solely use of traditional reinforcement such as large jointless structures, floors with special coatings and water- respectively liquid-tight structures. Very successful practical experiences have confirmed the concept of combined reinforcement and pointed out their advantages. Practical experiences and available theoretical basics will give a strong support for an increasing use of combined reinforcement for crack control in the nearby future.

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