THIN STEEL FIBER REINFORCED CONCRETE OVERLAYS AND INLAYS ON OLD PAVEMENTS A TEN-YEAR BELGIAN EXPERIENCE

Ir. K. **Verhoeven**, Belgian Cement Industry Collective Research Center, Brussels
Y. **Vancraeynest**, Bekaert N.V., Zwevegem, Belgium

1. INTRODUCTION

Invented in the late sixties, fiber reinforced concrete has been studied and tested intensively and put to subsequent use in a variety of demonstration projects. After a long incubation period, steel fiber concrete has become a composite recognized across the globe.
The world market is presently estimated at 100,000 tonnes.

Steel wire fibers have been used in the paving sector now for more than 15 years. In the main, steel fibers enjoy a successful world-wide application in industrial flooring (+/- 75 million m^2). The exceptional technical characteristics of steel fiber concrete enable a more efficient use of the concrete, so that steel fiber concrete floorings are usually thinner under the same load than floorings using reinforcement mats. We find other applications in roadways, harbour & airport pavements and parking areas.

Tollbooth paving is used in France and at the 'Liefkenshoek' tunnel in Belgium, where reinforcement mats cannot be used due to the presence of electrical loops.

Works carried out at the beginning of 1980 using full depth petrol station lanes and parking areas under heavy load are still in good condition. A large number of SFRC Secondary Road Constructions such as pipes, water collecting channels, and channel covers are also used. Concealed gulleys were made of sliding forms in steel fiber concrete.

Since 1972 small and larger full depth road projects have been carried out in the United States and Belgium with thicknesses of between 20 and 25 cm, depending on the road type. Results show that Steel fiber concrete is able to comply with modern paving requirements due to its very tough and fatigue resistant characteristics. Yet over the last decade more attention has been turned to the renovation of existing road pavements, whereby economically and technically justifiable solutions have been sought.

Thanks to the experience accumulated in fiber types, fiber quantities, mixing and processing, attention was again turned in 1982 to thin steel fiber concrete overlays. Between 1982 and 1987, Belgium constructed 129,000 m^2 of test sections using steel fiber concrete overlays. In the years that followed, decrees and prescriptions were drawn up on the basis of evaluations, which have led to several practical realizations.

2. STEEL FIBER REINFORCED CONCRETE AS A ROAD BUILDING MATERIAL

2.1. Steel fiber reinforced concrete

Steel fiber reinforced concrete is composed of cement, coarse aggregate, sand and water, just like plain concrete, to which relatively long (15 to 60 mm), and thin (diameter of 0.40 to 1.0 mm) steel particles have been added. At first sight, SFRC is quite similar to normal reinforced concrete. Yet, there is an appreciable difference : SFRC is reinforced homogeneously. It is a homogeneous composite material and behaves as such.
The thin steel fibers are spread evenly throughout the concrete mass in amounts corresponding to the user's needs.

Advantages of fibred concrete over plain concrete :

- high flexural toughness
- high crack strength
- very high energy absorbing capability
- high fatigue resistance and shear strength

Steel fibers are available in a wide variety of Types and Shapes, and different steel fiber manufacturing processes are used, including :

- cutting cold drawn wire
- slitting sheet steel
- melt extraction process
- milled steel fibers

Fibers can be straight, but the majority are shaped in such a way as to improve their anchorage in the concrete.

The most useful parameters for describing fibers to date are :

- aspect ratio (length/diameter ratio)
- fiber tensile strength
- geometrical shape

The steel fiber reinforced concrete overlay program has been realized with glued and hooked Dramix® fibers (N.V. Bekaert) : type ZC 50/50 and type ZC 60/80 (L/D 75).

These fibers have following characteristics :

- L/D ratio, 100 and 75 respectively
- Tensile strength min. 1,200 N/mm^2
- Hooked ends to improve anchorage in the concrete
- Glueing together in strips of 20 - 30 fibers. The bundling of fibers is done with a soluble glue.

In the mean time, standards have been set in some countries and are under preparation in others.

- ASTM A 820-90 (steel fibers for fiber reinforced concrete)
- ASTM C 1018-85 (flexural toughness)
- JSCE SF (the Japan Society of Civil Engineers - Steel fibers)

Standards allow not only a determination of the characteristics of SFRC, but also an evaluation of the reinforcing efficiency of each of the available steel fibers.

2.2. Toughness values for Steel fiber Concrete

The main difference between plain concrete and steel fiber concrete is the post crack behaviour, i.e. the ability to withstand load even after crack formation. This toughness (the so-called equivalent flexural strength) is decisive in the flexural strength design value, and a direct measure of shock resistance and the ability to absorb energy in a fatigue load situation.

The standard used in Belgium specifies test methodologies for the flexural strength and the flexural toughness of steel fiber reinforced concrete using third-point loading. The test specimens measure 150 x 150.
The span is equivalent to three times the sample depth.
Flexural toughness is derived from the area below the load definition curve until deflection at the loading point reaches 1/150 of the span, usually 3 mm.

Fig. 1 : Flexural Test Set-up

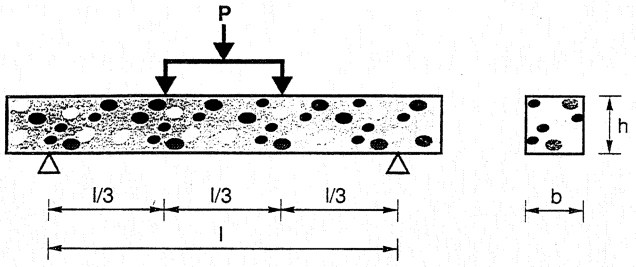
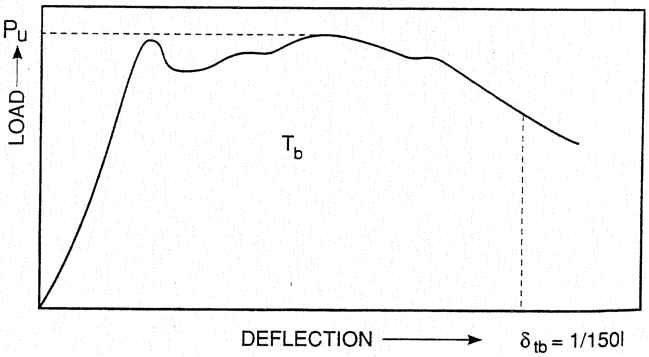


Fig. 2 : Definition of equivalent flexural strength



Equivalent flexural strength is calculated using the following equation.

$$f_e = \frac{T_b}{\delta_{tb}} \cdot \frac{L}{b \cdot h^2}$$

$$f_u = P_u \cdot \frac{L}{b \cdot h^2}$$

In which : f_e : equivalent flexural strength (N/mm^2) (kgf/cm^2)

T_b : flexural toughness (kgf.cm) (J)

δ_{tb} : deflection of 1/150 of span

Apart from the quantity of fibers per m^3 of concrete, the toughness of SFRC is directly related to the type of fiber used (L/D, Anchorage, Tensile Strength and fiber ductility).
The characteristics peculiar to SFRC have raised an interest in its use for road constructions. The increased equivalent flexural strength and the high energy absorption capacity of SFRC are the main characteristics influencing the design of thin SFRC overlays. High fatigue resistance allows higher stresses and hence thinner slabs. Fatigue tests illustrate that non-reinforced samples fail at a stress equivalent of ultimate flexural strength.
While, depending on the fibre type and quantity, with a good steel fiber concrete, SFRC concrete will have fatigue strengths of about 75 to 90 % of the critical crack strength. (ref. 3-4)

2.3. The Recommendations of the Belgian Public Works Department

Based on the definition and Standards for SFRC and results from the large research projects, the Belgian Public Works Department, in cooperation with the Belgian Cement Industry and the Belgian Road Research Center have worked out important recommendations for SFR Concrete Overlays.

o Definition of the fiber :

* Fibers must be produced from steel to improve their anchorage in the concrete
* (equivalent) diameter : 0.40 to 0.80 mm
* length : 30 to 60 mm
* tensile strength : min. 1,100 N/mm²

o Concrete :

Grain distribution :

The maximum nominal size of the aggregate :
≤ 32 mm where nominal thickness of the pavement is ≥ 16 cm.
≤ 20 mm where the nominal thickness of the pavement is < 16 cm

* Composition :

The minimum quantity of steel fibers must be chosen so as to obtain an equivalent flexural strength equal to min. 3.5 N/mm² in 28 days.

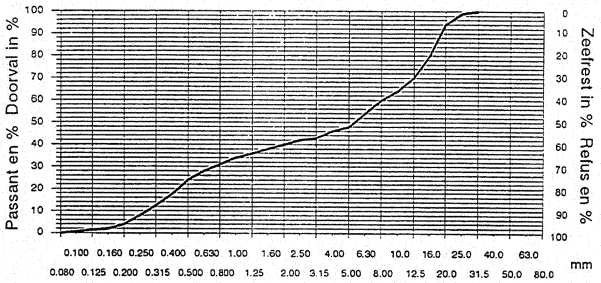
2.4. Concrete mix formula

According to a study carried out by the Research Center of the Cement Industry, and for an easily workable, good quality Steel fiber Reinforced Concrete, the following mix formula has been used.

Materials (wet)	Quantity per m³ of concrete
Portland Cement	400 kg
River sand O/2	730 kg
Crushed Gravel 2/20	1,100 kg
Steel Fibers	
Dramix ZC 50/50	30 kg
Water	184 kg
Plasticizer	0.6 l.

Use a continuous grading of the aggregates. The water cement ratio should be about 0.45 and under no circumstances may this exceed 0.50.
The average compressive strength of the concrete after 28 days is about 60 MPa.
Resistance to bonding after cracking is about 4.0 MPa.

Fig. 3 : Granulometry inert aggregates



3. TEST SECTIONS (1982-1987)

3.1. Realizations (129,000 m²)

At the 4th International Conference on Concrete Pavement Design and Rehabilitation (Purdue 1989), the subject was reported on pages 47-61 under the heading "Thin Overlays of Steel Fiber Reinforced Concrete and Continuously Reinforced Concrete - State-of-the-Art in Belgium".
This text includes the main characteristics of the section concerned under tables 1 and 2.

The main conclusions at that time were essentially focussed on bonding behaviour. These are recounted in the following paragraphs.

- On a bituminous underlayer.
  The results can be labelled as very good. Up to now, the bond seems to be remarkable and durable. The best results were obtained on a new levelling course with an overall open structure (1.5 to 2 N/mm²). For milled old asphalt layers, the bond strength lies between 25 and 50 % lower. Clearly the behaviour of the asphalt layer will need close monitoring in the future.
- On old concrete pavements.
  The bond seems to be a fundamental criterion for success. The preparation work requires care and workmanship. Only an adequate bond provides the opportunity to overlay at a thickness of less than 15 cm.

  If the bond is effectively achieved, steel fibers do not seem to offer economically justifiable advantages.

  o Intensive roughening of the old concrete surface by milling or shot blasting is needed if a durable bond is to be guaranteed. Grouting does not seem to offer much (if any) improvement.

  o Direct re-surfacing on concrete is only a viable option when the condition of the old pavement is still relatively good. If not, localized preparation work, by replacing badly distressed slabs, will be necessary. The direct re-surfacing of old continuously reinforced concrete could very well be targeted here.

- o As the rehabilitation of an old concrete road is for the most part considered only when severe damage has already occurred, a separation or leveling layer will generally be of vital importance.

All in all, experience with "concrete on concrete" bonded overlays shows that the technique is still in its experimental stage, and all the more so since reflective cracking cannot be effectively avoided and controlled using steel fibers.

3.2. Evaluation after 5 to 10 years

Sections 1 and 2, on which SFRC was applied directly on top of the existing concrete layer, did not achieve the desired results. Section 1 was removed in February 1992 (after 9 years). Substantial longitudinal cracking and strong fragmentation occurred due to a lack of adhesion in the joint area (fig. 4).
Under the given circumstances, the fibers did hold the fragments together to a certain degree.
Drawing from this experience, an intermediate bituminous layer was applied to the old concrete paving for the next sections.
The result is that the overlay becomes less 'thin'.

The best results were obtained with a 4.5 to 6 cm thick intermediate bituminous layer (sections 3, 4 and 5), and also with a partially planed and scarified old asphalt pavement (sections 6 and 7).

Fig. 4. Section 1 - Cracking and fragmentation near most of the joints of the heavy loaded right lane



Table 1 : Characteristics of experimental thin overlays in steel fiber reinforced concrete on old concrete pavements (until 1987).

experimental site	with direct bond		with asphalt separation course		
	1. GENT	2. VIERSET	3. MALDEGEM	4. ASTENE	5. ZELZATE A
date of construction	June 1983	July 1983	Oct. 1982	Sept. 1987	Sept. 1987
area (m^2)	27,500	30,000	13,300	11,300	8,000
old pavement condition	heavily scaled but good structural condition	scaled but fairly good structural condition	badly deteriorated pumping and stepping	very bad many cracks, pumping and fragmentation	scaled but good structural condition transverse cracks
old joints	contraction dowels	expansion	expansion	expansion	contraction dowels
base course	crushed stone	none	none	crushed stone	crushed stone
traffic	very heavy (industrial)	light	rather heavy	heavy (> 10,000 veh./d)	heavy
preliminary work	- simple cleaning - cleaning + grout - milling - milling + grout	- milling - milling + grout	- local slab-breaking - 6 cm open graded bituminous separation course	- general slab-breaking - 6 cm asphalt separation course	- 5 cm asphalt separation course - steel map above existing cracks
overlay thickness	10 cm	10 cm	10 cm & 12 cm	12 cm	10 cm and 8 cm
"Dramix" kg/m^3 steel type fibers	40 50/50	40 50/50	50 50/50	30 50/50	30 50/50
slab length	10 m = old joint pattern	10 m = old joint pattern	15 m (500 m without joints)	5 m	9-10-11 m = old joint pattern
evaluation 1992	general fragmentation in joint area due to debonding		generally good and durable bond with separation lager		
	removed in 2/'92		only 1 crack		

Section 3, the oldest (10 years), behaves very well (fig. 5).
Only one angle crack has appeared on a transverse joint and this despite the large slab length of 15 m. As expected, the neoprene joint filling poses problems. Unavoidable high joint movement in a number of transverse joints cannot be followed up by the neoprene strips. Shortly, these joints will require a thorough overhaul with ordinary hot joint sealant.
Cracks at variable distances of between 10 and 60 m in the section without transverse joints are still behaving well.
There are no signs of developing damage.

After 4 years of heavy traffic, section 4 (fig. 6 & 7) is still in very good condition. No angle cracks have been detected, except for a zone of around 100 m. At that place however, a total of 17 short length cracks have appeared at about 50 cm from the pavement edge. This is probably related to the bad condition of the underlying old concrete layer in the zone.

Section 5 is however highly susceptible to the "curling" phenomenon. Due to edge load effects, 29 % of the slab corners near the adjoining concrete hard shoulder are cracked (fig. 8).
5 % of these affect upward corners and 20 % affect downward corners. Three transverse joints show both upward and downward corner cracks.

Core drillings carried out in 1990 have shown that the thin intermediate bituminous layer adheres well to the steel fiber concrete. However, the asphalt layer does not adhere to the old (and fouled) concrete surface, so the curling effect involves this layer too. This layer has undergone serious repetitive wheel loads, sometimes with crumbling as a consequence (fig. 9).
The problem can be avoided by pointing the longitudinal road marks farther away from the border.

Fig. 5. Excellent behaviour of oldest section 3 (1982)



Fig. 6. Section 6 (1987)



Fig. 7. Construction of section 6. Notice the bituminous separation layer.



Fig. 8. Section 5 - Corner cracks due to curling



Fig. 9. Section 5 - Deterioration of the non bonded bituminous layer due to traffic hammering

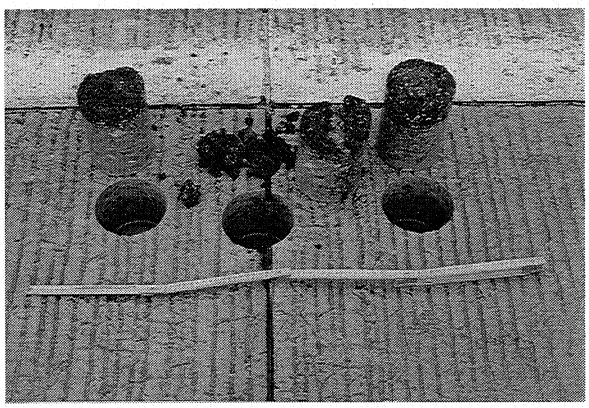


Fig. 10. Section 7 - Inlay



Fig. 11. Section 6 - An unlucky number for bond ...

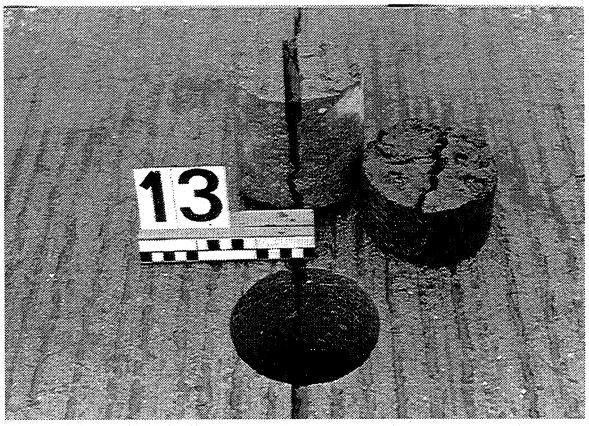


Fig. 12. Section 9 - White topping with 12 cm SFRC (1989)



With a measured average thickness in steel fiber concrete of 12.1 cm (as opposed to the prescribed 10 cm), this differs little from section 4 (Astene) which was constructed during the same period. An explanation must be sought basically in slab length (only 5 m on section 4) and in a better bond between the intermediate bituminous layer with the broken old concrete surface layer. Moreover the edge load is less pronounced on section 4 because of the presence of an earthen roadside which keeps the traffic further from the slab edge.

Numerous corner cracks have also been detected on section 8 (Jalhay). 15 % of the corners are indeed cracked. Here too adhesion with the bituminous underlayer is very good (average adhesive strength 1.36 N/mm^2) but there is no adhesion with the underlying leen concrete. This cracking behaviour in the 15 m slabs (fig. 9) can be attributed to the curling of the thin steel fiber concrete layer with the attached asphalt layer.

The inlays of the sections 6 and 7 (fig. 10) are better able to withstand this curling effect.
At section 6 only 2 % of the corners along the bituminous hard shoulder are cracked. Remarkable here is that only 3 % of the corner cracks appear in the right lane, near the longitudinal center joint. This gives rise to two conclusions :

on the one hand, the thicker remaining old asphalt underlayer is not dragged along by possible curling effects. This was equally not the case on section 3 (Maldegem) where this layer actually had an average thickness of 10 cm due to the necessary flattening of both the transverse and longitudinal profiles. On the other hand, adhesion with the milled off asphalt layer is more variable. Core drillings have highlighted slab edges with interrupted adhesion (fig. 11). This can evidently be attributed to dirt on the milled off surface. A bituminous adhesive layer would appear essential for realizations in the future.

At section 7 too, only 2 % of the corners are cracked along the hard shoulder.

All the corner cracks at the six test sections discussed above, with asphalt separation courses, cold scarified old asphalt pavements or asphaltic strengthening courses, can be said for the most part, i.e. 90 %, to be fine to very fine cracks, which have developed only slightly until now. Therefore the fibers play a definite delaying role.

4. RECENT CONSTRUCTIONS AFTER 1987 (85,000 M2)

Drawing upon accumulated experience, 4 more sections have been constructed since 1989.

Section 9 (fig. 12) is a 12 cm thick white topping layer on a heavily rutted asphalt pavement.

Sections 10, 11 and 12 (fig. 13) are overlays on old concrete pavements, each with an intermediate bituminous layer.

With relation to earlier test sections, the slab length was reduced here to 4.5 m. At section 12, the old cracked concrete paving was sprayed with an acidic bituminous emulsion in an attempt to improve adhesion.

All these sections are showing satisfactory behaviour, but as yet it is too early to draw conclusions.

5. CONCLUSIONS

The conclusions drawn in 1989 in relation to thin "concrete on concrete" overlays, recounted in paragraph 3.1., are still applicable. Even if the adhesion problem could be solved, the fact remains that any Belgian roads likely for selection are for the most part too badly damaged for direct overlaying.

Viewed realistically, it can said that an insulating intermediate layer is practically unavoidable. Naturally, this results in a less 'thin' SFR overlay, but on the other hand experience shows that thicker (20 cm) classic concrete overlays are best constructed on an intermediate bituminous layer.

The best results were obtained when an intermediate bituminous layer of between 5 and 6 cm was laid over the old concrete pavement (sections 3, 4 and 5).
It appears the best solution would be to break the old, mostly unstable and fairly to heavily cracked slabs.

Adhesion to this underlayer does not generally seem to cause many problems. Long slabs subject to curling appear to drag the bituminous layer along too, eventually leading to corner cracks. The oldest section, section 3, is not however affected by this phenomenon ; here the intermediate layer is 10 cm thick.
The thicker SFRC sections 4, 6 and 7 (12 cm) also show fewer corner cracks.

So, a good concrete mix with less than 200 l water for each 400 kg/m^3 cement, short slabs (5 m), general slab breaking, a not too thin bituminous separation layer (6 cm) preferably with an open structure, possible spraying with a bonding bituminous emulsion on the old concrete, and good workmanship seem to be the ingredients for a successful thin overlay on an old concrete pavement.

Fig. 13. Section 10 - Construction of 10 cm SFRC on top of a bituminous separation layer



Thin overlays (white topping), or mostly inlays, on asphalt roads showing signs of ruts are planed off over the desired depth, provided a sufficient thickness of asphalt remains. To obtain a good adhesion between the asphalt and steel fiber concrete, the milled off asphalt surface must be carefully cleaned.
A bituminous emulsion can also be used here to improve adhesion. Short slabs (5 m) and a concrete mix with W/C $\leq$ .50 are of course also required here.

Edge load can be maximally avoided by providing extra width of the right lane.

REFERENCES

1. Verhoeven K.
   Thin overlays of steel fiber reinforced concrete and continuously reinforced concrete, state of the art in Belgium. Centre National de Recherches Scientifiques et Techniques pour l'industrie cimentenière.
   International Purdue Conf. 1989.

2. Verhoeven K.
   Recouvrements minces en béton de ciment.
   Centre national de recherches scientifiques et techniques pour l'industrie cimentenière.
   RR Cric 52 - f - 1990

3. Ramakrishnan, U. and Josifek Charles : "Performance characteristics on flexural fatigue strength on concrete steel fiber composites" procedure of the international symposium on fibers. Reinforced concrete. Dec. 1987, Madras, India pp. 273-284

4. Ramakrishnan, U. : Oberling, C. and Tatnall, P. : "Flexural fatigue strength of steel fiber reinforced concrete".
   Fiber reinforced concrete properties and applications, sp-105, American Concrete Institute, Detroit 1989, pp. 225 - 245.

Table 2 : Characteristics of experimental thin overlays in steel fiber reinforced concrete on deteriorated asphalt pavements (until 1987).

experimental site	"inlay"		strengthening course
	6. GAURAIN	7. VAULX	8. JALHAY
date of construction	May 1984	Sept. 1987	May 1985
area (m^2)	6,500	3,500	27,500
old pavement condition	heavily rutted	heavily rutted	badly deteriorated
foundation	lean concrete	lean concrete	crushed stone
traffic	very heavy	very heavy	light
preliminary work	cold scarification	cold scarification	structural strengthening with 6 cm asphalt on lean concrete of variable thickness
overlay thickness	10 cm and 12 cm	12 cm	10 cm
"Dramix" kg/m^3 steel fibers type	30 50/50 and 60/80	30 60/80	35 and 40 60/80
slab length	10 m and 15 m	10 m	15 m
evaluation 1992	behaviour can be considered as good to very good. due to local debonding minor curling occured.		behaviour is considered as fair. bond is not always achieved due to less durable bond with dense asphalt strengthening course.

Table 3 : Characteristics of SFRC-overlays since 1989.

site	white topping on asphalt	on old concrete pavement with asphalt separation course		
	9. AALST	10. ASSENEDE	11. ZELZATE B	12. KLUISBERGEN
date of construction	June 1989	May 1990	June 1990	Sept. 1991
area (m^2)	10,000	50,000	8,000	20,000
old pavement condition	heavily rutted	good structural condition transverse cracks	good structural condition transverse cracks	cracks pumping and stepping
old joints	-	contraction dowels	contraction dowels	expansion
base course	crushed stone	crushed stone	crushed stone	crushed stone
traffic	heavy	heavy	heavy	rather light
preliminary work	cold scarification	4.5 asphalt separation course	4.5 cm asphalt separation course	- general slabbreaking - 6 cm asphalt separation course
overlay thickness	12 cm	10 cm	10 cm	12 cm
"Dramix" content kg/m^3 fiber type	30 50/50	30 60/80	30 50/50	30 50/50
slab length	10 m	4.5 à 6 m	4.5 à 6 m	8 m
evaluation 1992	behaviour after 3 years looks to be promising			