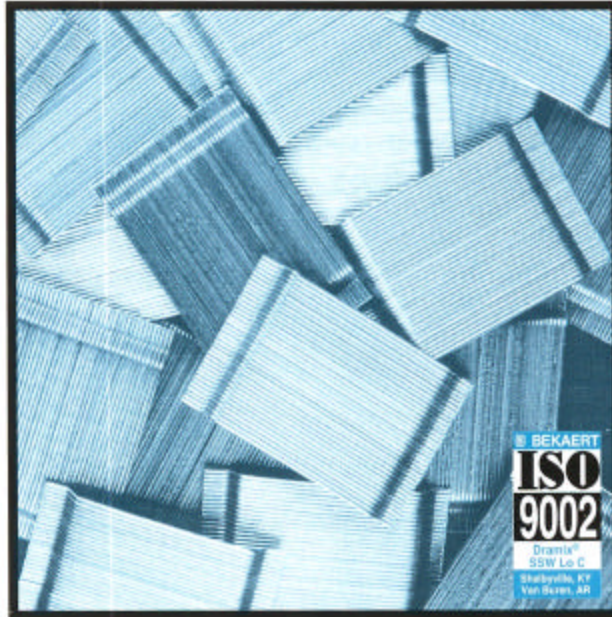


Dramix[®]



The properties
of
Dramix[®] steel fiber concrete

The properties of Dramix® steel fiber concrete

Steel fiber concrete

Fiber reinforced concrete is a composite material whose bearing strength is determined by the combination of its two constituent parts: the concrete and the fibers.

$$P_c = P_m + P_f$$

This assumes, there is a close interaction between the two materials. Where a load is applied, this results in a deformation of the composite, this interaction is governed by:

- the ratio between the elasticity moduli ($n = E_f/E_m$)
- transmission of the stresses from the concrete to the fibers.
- the uniformity of fiber distribution

Dramix® steel fibers with hooked ends maximize these interaction factors because of:

- the use of high tensile strength drawn steel wire
- the anchored hooked ends of the fibers, which make it possible to use the whole length of the fiber to transmit the maximum amount of force and prevents any splitting force from being exerted on the concrete.
- a uniform distribution of the fibers in the concrete as a result of the easy handling of the Dramix® fiber bundles.

The deformation behavior of Dramix® fiber concrete

In the elastic phase (before micro-cracking), the tension in the composite may be calculated as follows:

$$\sigma_c = \sigma_m(1 - v_f) + k \times \sigma_f \times v_f = \sigma_m \left[1 + \left(k \frac{E_f}{E_m} - 1 \right) v_f \right]$$

Due to the constraints of mixing, the quality of fibers in the mix (v_f) must not exceed 2% by volume, or 160 kg per m³ of concrete. Given a complete three dimensional orientation of the fibers, the factor k will not exceed 1/3.

The ratio of the elasticity modulus of the fiber to that of the concrete, E_f/E_m is in the order of 10, so that in uncracked concrete:

$$(\sigma_c)_{\max} = 1.05 \sigma_m$$

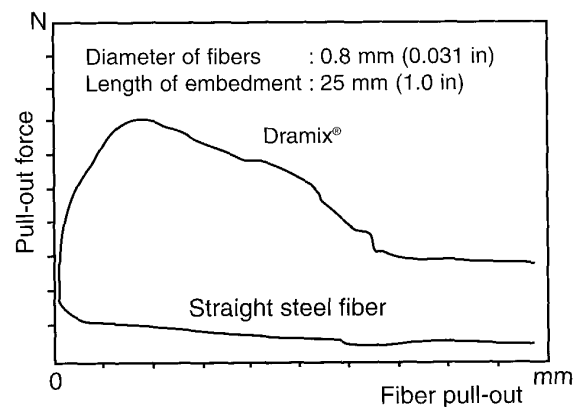
The addition of fibers therefore produces only a slight increase in the resistance to microcracking in the composite when compared with the resistance of unreinforced concrete σ_m .

Reinforcement with steel fibers realizes its full value in the post elastic deformation phase. The sudden brittle failure of unreinforced concrete is transformed into a slow controlled crack propagation under the influences of forces such as compression, tension, flexure, shear, shrinkage and creep.

The intrinsic qualities of Dramix® steel fibers are fully revealed when they span hairline cracks in the concrete and absorb the tensile forces present.

Fig.1

Typical diagram of the pull-out strength of straight and hooked steel fibers.



This process is related to the straightening of the fiber hooks which continues until a high maximum pulling-out force is reached (**Fig. 1**) (1). To avoid sudden failure of the concrete, the quality of the steel is selected so that the breaking strength of the fibers is only exceeded in exceptional cases.

When the concrete is further loaded in tension or flexure, the width of the crack will increase due to the pulling out of the fibers as the hooks undergo plastic deformation (see fig. 1). This plastic deformation under high tensile stresses is one of the principal advantages of Dramix® fibers. It is this characteristic which allows the steel fiber concrete to achieve a high degree of toughness or residual strength. It therefore follows that hooked Dramix® fibers are ideally suited for absorbing intermittent dynamic loads.

In the post elastic phase, the tension in the composite can be calculated approximately by supposing $\sigma_m = 0$, so that:

$$\sigma_c = k \times \sigma_f \times v_f$$

The strength of the composite can be greatly increased if measures are taken to position the majority of the steel fibers in predetermined planes (thus increasing the value of k) (2). This can be easily achieved when using long Dramix® fibers in thin concrete elements. Furthermore, the higher the length to diameter ratio of the fiber and the better the fiber is anchored into the concrete, the greater the effective tensile strength of the fiber becomes. Based on these findings, Dramix® fibers have been designed so that long fibers are supplied in bundles for ease of handling and mixing and hooks are formed at both ends to achieve maximum anchorage.

The best illustration of the difference between ordinary concrete and steel fiber concrete is shown by load-deformation curves under specific loading conditions. It is also from here that the differences in performance between different types of steel fibers can be seen.

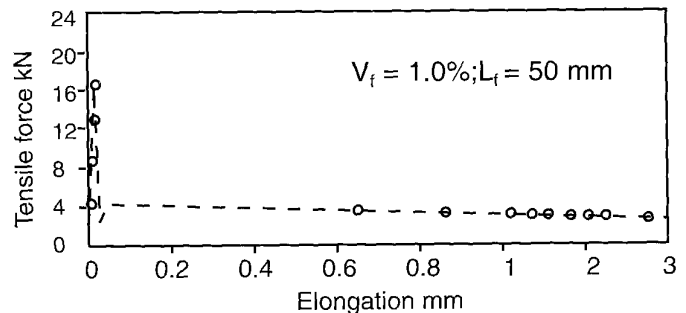
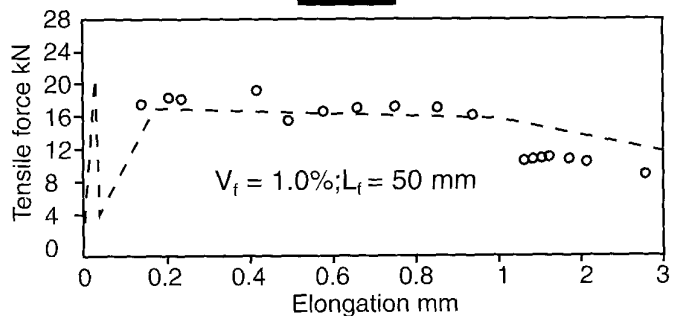
Static loads

Tensile load

The elongation of dumb-bell-shaped concrete samples as a function of the axial tensile force is shown in **figure 2** for fiber concrete reinforced with Dramix® ZC 50/.50⁽¹⁾, and in **figure 3** for straight steel fibers of the same dimensions (3). The difference in residual tensile strength after the appearance of the first crack is attributable solely to the better anchorage provided by the hooked ends.

With Dramix® ZC 60/.80⁽²⁾ fibers, residual tensile strengths from 1.0 to 2.0 MPa (145 psi to 290 psi) can be achieved with quantities of fibers between 40 and 80 kg/m³ (57 and 104 lb/yd³) (16).

Fig. 2



(1) The Dramix® ZC 50/.50 fiber has a length of 50 mm and a diameter of 0.50 mm. This fiber is replaced in 1997 by the Dramix RC-80/50-BN with a length of 50 mm and a L/D-ratio of 80 (diameter 0.62 mm)
 (2) The Dramix® ZC 60/.80 fiber has a length of 60 mm and a diameter of 0.80 mm. This fiber is replaced in 1997 by the Dramix RC-80/60-BN with a length of 60 mm and a L/D-ratio of 80 (diameter 0.75 mm)

The properties of Dramix® steel fiber concrete

Distinctly superior tensile strengths can be obtained by impregnating mats of steel fibers with a grout (4). Ultimate strengths of 20 MPa are achievable if the volume of fibers goes up to 10% (fig. 4).

Fig. 4

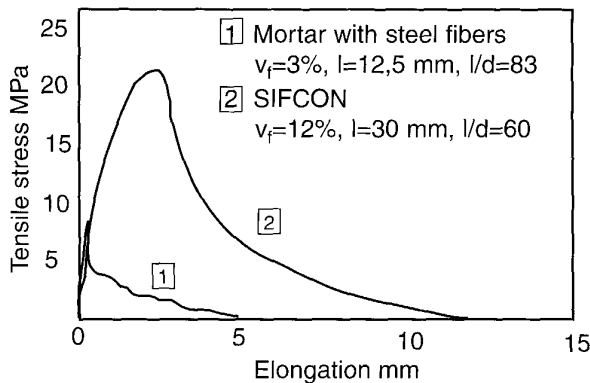
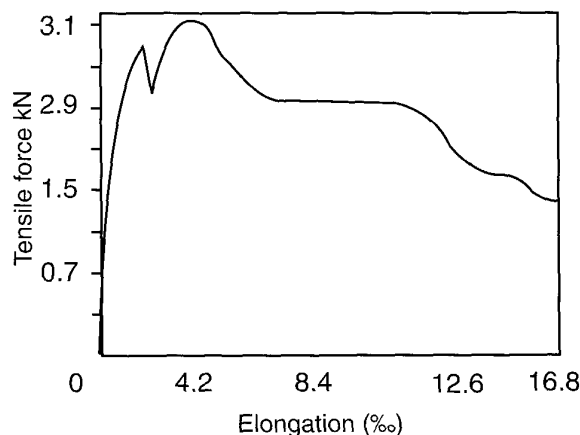


Figure 5 illustrates the long lasting tensile strength property of steel fiber concrete. After 23 years of aging in the open air, the composite material, which contained 160 kg of fibers per m^3 , had a tensile strength greater than 5.0 N/mm² and in addition displayed remarkable behavior with regard to high deformation capacity i.e. toughness.

Fig. 5



Flexural load

The behavior of steel fiber concrete subjected to flexural load is determined by the strength of the tensile zone. Just as in the case of tensile strength, flexural strength and pseudoplastic behavior after cracking are positively influenced by the anchorage of the hooks of the Dramix fibers. This is illustrated by figure 6a and 6b.

Fig. 6a

Determination of behavior after cracking of steel fiber concrete according to standard ASTM C 1018.

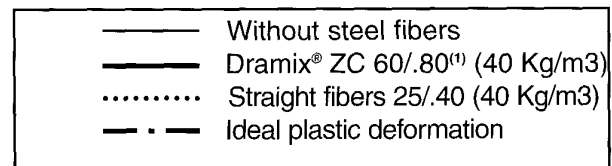
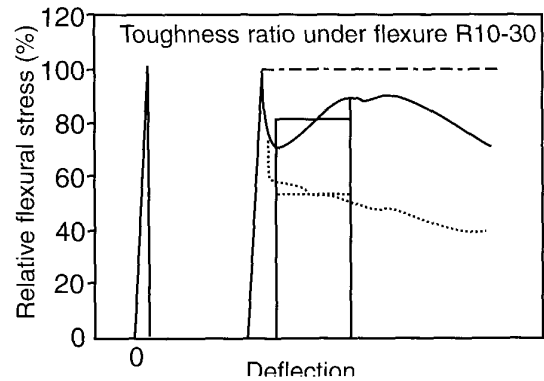
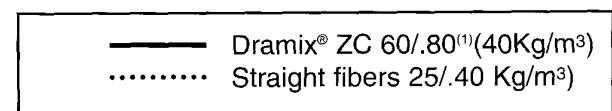
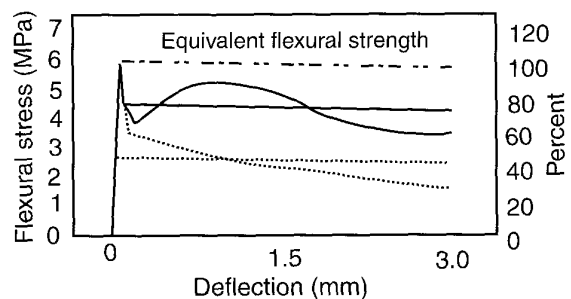


Fig. 6b

Determination of behavior after cracking of steel fiber concrete according to standard JSCE (Japan).



(1) See note 2 on page 3.

The pseudoplastic behavior of the composite material depends very much on the type and quantity of steel fibers added. It is possible to evaluate this characteristic by using standardized test methods to determine a mean value of strength after cracking. This equates to a conventional flexural strength which then serves as a base for methods of design (6).

According to standard ASTM C 1018-89 (7), a mean value is calculated on a segment determined from the load-deflection curve, e.g. between 5.5 and 15.5 times the deflection found when the first crack appears (*fig. 6a*). R 10-30 then represents the ratio between this mean value and the value observed at the first crack.

Japanese specifications JSCE (28) define the “equivalent flexural strength” (fe-3) as the mean flexural stress exerted over the deflection interval between zero and 3 mm (*fig. 6b*). The ratio between this equivalent flexural stress and the flexural strength of plain concrete represents Re-3.

The ratios R 10-30 and Re-3 indicate the degree to which the toughness of steel fiber concrete approaches or even exceeds that of an ideal plastic material. Low values of R 10-30 indicate a small movement of the fibers before gripping, while a low value of Re-3 indicates fiber breakage or a total failure of adhesion. For design purposes, the use of Re-3 is recommended when high deformation energy is to be absorbed or when intermittent loadings occur (industrial floors, highways, machine bases, protective constructions, tunnel wall linings, etc.).

The influence of the fiber type on the R values is shown very clearly by the data in *figures 6a* and *6b* and also in the table below.

40 kg/m ³ (67 pcy)	R 10-30	fe-3	Re-3
Straight steel fibers 25/.40	54%	405 psi	47%
Dramix® ZC 60/.80 ⁽¹⁾	82%	680 psi	78%

Within the limits of statistical variations, these ratios are independent of the strength of the concrete, so long as the characteristic compressive strength does not exceed 50 MPa (7250 psi).

These ratios increase with increasing fiber content. The relation between these two factors constitutes the “identity card” of a given fiber type. This technical information is indispensable for design calculation and for comparing different fiber types.

The high toughness of fiber concrete may be effectively used to advantage when combined with traditional reinforcement in concrete beams (8). The combined effect of reinforcing bars and steel fibers makes it possible to build structures which are highly resistant to dynamic loads. Even in situations where the Dramix® fiber reinforcement is limited to only part of the height of the beam this is sufficient to significantly reduce the size of cracks.

(1) See note 2 on page 3.

Compressive load

Concrete can withstand large compressive forces but will finally fail because of the formation of cracks resulting from tensile stresses perpendicular to the direction of compression. When the concrete is reinforced with fibers a small volume of fibers is not sufficient to significantly increase the compressive strength when the loading is in one direction only. This is seen in the experimental findings reproduced in **fig. 7**.

On the other hand, reinforcement with steel fibers does increase the spalling resistance of the concrete, to the extent that it is possible to avoid explosive collapse, e.g. in high strength concrete (**fig. 8**) (10). The main application of the property is in roof support blocks in mines.

Fig. 7

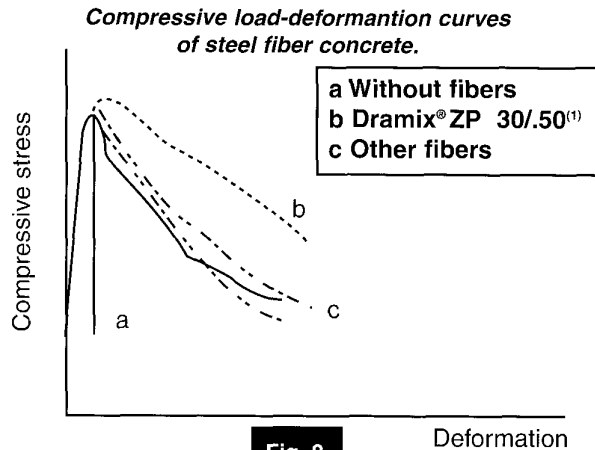
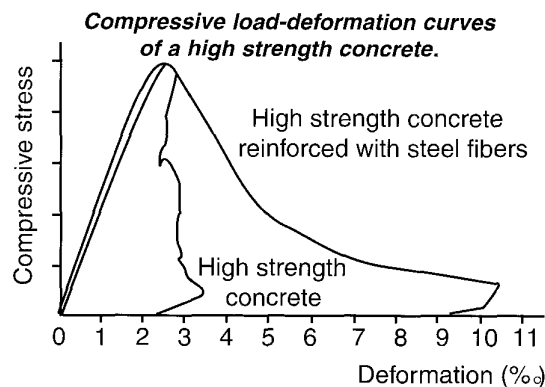


Fig. 8



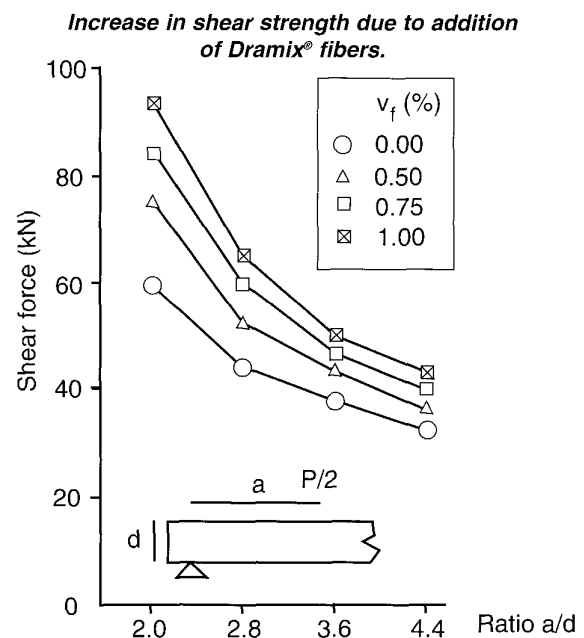
In many applications, such as slabs and roof shells, concrete undergoes bi-directional compression. In these cases a considerable increase in compressive strength is observed. The use of Dramix® fibers, 0,5% by volume, has produced an increase of 50% (11).

Shear load

Experiments have shown that Dramix® steel fibers, used in conjunction with primary bar reinforcement, are capable of converting a brittle failure by shear forces into a more controlled flexural failure (12, 13). As can be seen from **fig. 9**, in trials with hooked Dramix® fibers it is possible to achieve a distinctly superior shear strength. It follows that Dramix® steel fibers make it possible to design concrete components with no risk of shear, and to replace reinforcing stirrups either wholly or partially. Methods of calculation have been developed for this purpose (15, 16).

These positive effects have also been demonstrated experimentally for prestressed concrete components and deep beams. A high punching resistance has also been put forward as a solution to the problem of high shear stresses in concrete slabs (14).

Fig. 9



(1) The Dramix® ZP 30/.50 fiber has a length of 30 mm and a diameter of 0.50 mm. This fiber is replaced in 1997 by the Dramix RC-65/35-BN with a length of 35 mm and a L/D ratio of 65 (diameter 0.55 mm)

Dynamic loads

The reduction and control of cracking achieved with the Dramix® steel fibers result in a slowdown of the concrete internal degradation process due to dynamic loads. Steel fiber concrete may therefore undergo greater deformations, or under equivalent stress withstand a greater number of load cycles, than nonreinforced concrete.

Intermittent compressive load

When subjected to mono-directional compression, the fatigue resistance of steel fiber concrete is slightly better than that of plain concrete. Tests show an increase in the static compressive strength from 55% to 60-65% after one million load cycles (17). Studies of cases of permanent deformations have shown that at high stress levels steel fibers may prevent brittle failure while at low stress levels, steel fibers slow down the propagation of cracks. In both cases the life of the concrete is extended.

Intermittent tensile and flexural load

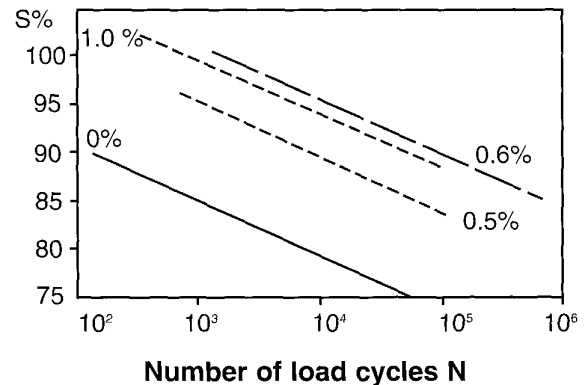
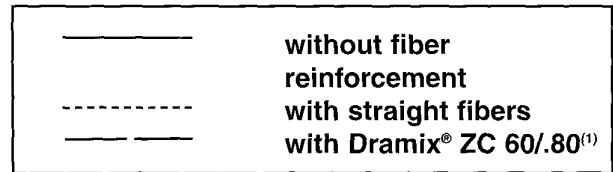
Fatigue resistance under tensile or flexural load is given by the number of cycles before failure (N) expressed as a function of the stress level S (**fig. 10**).

$$\log N = K (S_0 - S)$$

In this case, $S = \sigma/\sigma_0$ and $S = S_0$ for $N = 1$. The reference stress S_0 represents the first crack strength under static load.

Fig. 10

Typical fatigue behavior of concrete and of steel fiber reinforced concrete.



The quality and relative performance of the fiber reinforcement determines the magnitude of S_0 . They also determine the number of cycles N as a function of the relative load S. These are expressed in the table below in numerical values taken from **fig. 10**.

	V_f (%)	L/d	For N=1	For S=0.85	For N=2x10 ⁶
Concrete	0	-	$S_0 = 1.0$	$N = 1.10^3$	$S = 0.5-0.6$
Steel fiber concrete	0.5	75	$S_0 = 1.12$	$N = 72.10^3$	$S = 0.77$
Straight fibers (18)	1.0		1.16	380.10^3	0.81
Dramix® ZC 60/.80 ⁽¹⁾ (19)	0.6	75	1.18	900.10^3	0.83

In flexural tests, concrete beams which had not suffered external degradation after two million flexure cycles, showed an increase in flexural strength of 10% to 35% (20).

(1) See note 2 on page 3.

The properties of Dramix® steel fiber concrete

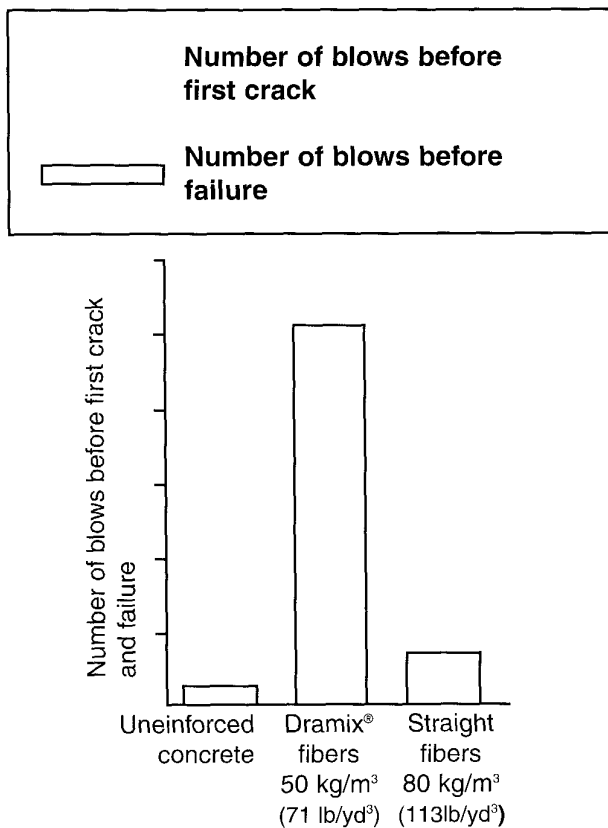
Impact loads

The capacity to absorb energy and the ductile behavior (toughness) of steel fiber concrete make this material extremely resistant to impact. In this case, the notably superior performances of concrete reinforced with Dramix® is explained by the fibers hooked ends which give a high dynamic resistance to pull-out.

Comparative experimental data is available for pendulum and falling weight tests (22, 23). **Figure 11** illustrates the results obtained using the ACI test method (24).

A steel fiber composite (SIFCON) has been developed for special applications where the strength requirements are particularly high. This comprises a fiber reinforcement of up to 10% by volume (27).

Fig. 11



A further improvement in impact resistance has been found when latex is used in steel fiber concrete (25) and when a welded mesh reinforcement is combined with steel fibers (26).

Conclusions

The addition of Dramix® steel fibers to concrete is an important step in research towards improving its properties. The areas of use are vast and expanding. Steel fibers for example, not only offer a solution for the low tensile strength of concrete, they also give a pseudo-ductile behavior to brittle concrete. Additionally they provide good energy absorption, which offers a technical solution to certain specific loading conditions.

Even a small addition of fibers can improve most of the characteristics of concrete. The extent of the improvement depends on the particular characteristic being considered. The table below shows several indices representative of concrete with Dramix® steel fibers having dosages not exceeding 1% (78.5 kg/m³ or 111 lb/yd³), as a function of the fiber type and the quality of the concrete.

Type of load	Index
Compressive	1 - 1.1
Flexural	• traction-flexion • shear • fatigue
	1 - 1.5 1 - 2.0 1 - 2.0
Impact	1 - 100

The data quoted in this brochure reflects the state of technology at the time of publication. However, the presence of inaccuracies in this brochure cannot be ruled out. The user of this brochure accepts this risk N.V. Bekaert S.A. disclaims all liability in regard to any loss or damage which may result from the use of the information herein

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