FIBRAFLEX®

Corrosion resistance
of the amorphous metallic fibres

SAINT-GOBAIN

1. General characteristics and description of the amorphous metallic fibres production process

Amorphous metallic fibres were developed in 1985 by a Saint Gobain Group's research center. Today, they are manufactured in its subsidiary Saint Gobain SEVA, located in France and sold under the brand "FIBRAFLEX®". They are available in the shape of a narrow ribbon (1 to 1.6 mm wide). The lengths are between 5 to 30 mm depending on the application.

This ribbon is made by hyperquenching a liquid alloy jet over a high speed rotating wheel (**Figure 1**).

This technique helps to obtain extremely thin ribbons (24 to 29 microns) with a very high quenching speed (by about one million degrees per second (**Figures 2 and 3**)).

Figure 1.

Diagram showing the hyperquenching process to produce the amorphous metallic fibres

Amorphous metallic fibre (Trade name : FIBRAFLEX)		
Composition	:	$(Fe, Cr)_{80}$ $(P, C, Si)_{20}$
Width	:	1 or 1,6 mm
Thickness	:	24 to 29 microns
Length	:	5 to 30 mm
Mechanical	:	≈ 1800 MPa
Density	:	7,2

Figure 2.

Characteristics of the amorphous metallic fibres

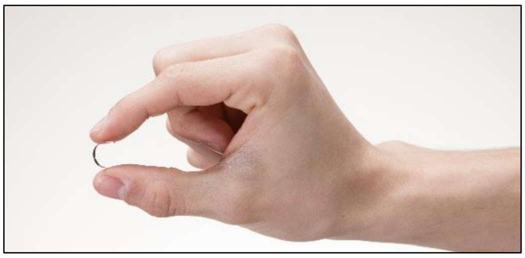

Figure 3.

Amorphous metallic fibres bent between two fingers

This quenching solidifies the liquid metal into amorphous state (non-crystalline) imparting it with three interesting properties :

- exceptional mechanical strength : in case of amorphous metallic fibres, the tensile strength is in the range of 1,800 Mpa ;
- flexibility in the transversal direction : a fibre can bend easily between two fingers ;
- very high corrosion resistance, a point that we are going to develop.

2. Intrinsic resistance to corrosion of the amorphous metallic fibres

Corrosion resistance of metallic materials is determined through the composition, stability and uniformity of the passive layer which forms on the surface of these materials, as well as through the kinetics of this passive layer formation.
In case of amorphous materials, it has been shown that the passive layer forms more rapidly, and if the alloy contains chromium, this is present in significant amount on the surface of the film, in the form of oxyhydroxydes of protective hydrated chromium.
In order to validate this point and compare it with other materials, potential intensity tests (**Figures 4 and 5**) have been carried out in two corrosive environments : a salt water bath (30 g/L) and a basic medium (NaOH) at very high pH (pH 13).
Following were the materials tested :- ferritic cast iron,

- stainless steel 18-8,
- amorphous alloy containing 5 % chromium (case of amorphous metallic fibres),
- amorphous alloy without chromium,
- crystalline alloy containing 5 % chromium.

Only the amorphous alloy containing 5 % chromium offers better performance than stainless steel, thereby confirming that these are combined influences of chromium and the amorphous state which helps in attaining a good resistance to corrosion.

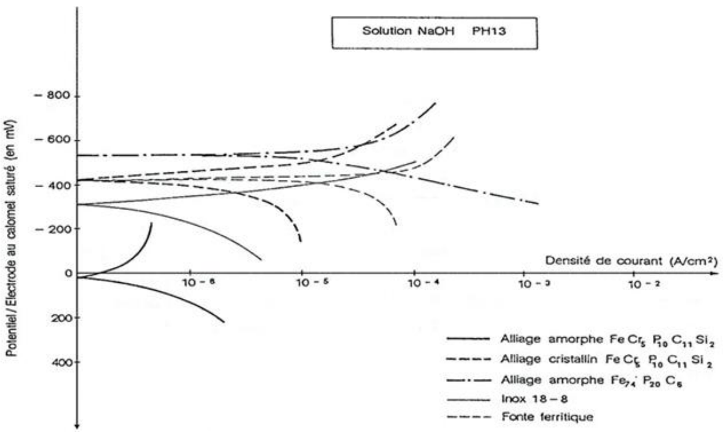

Figure 4.

Potential-intensity curves of various alloys in a NaOH pH 13 solution

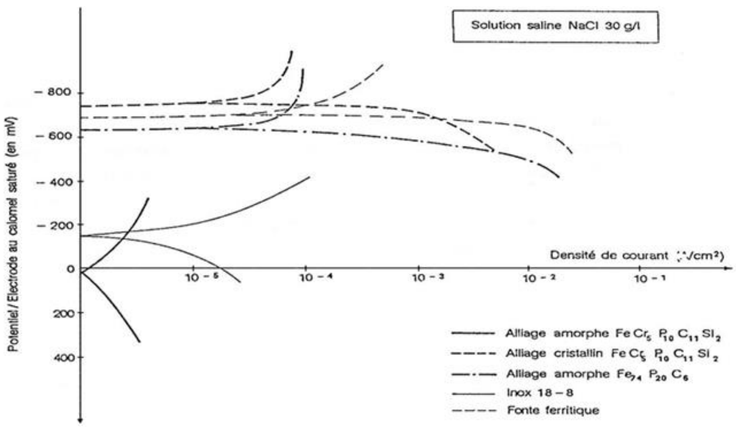

Figure 5.

Potential-intensity curves of various alloys in a saline solution NaCl 30 g/l

Close to these tests, the performance of amorphous metallic fibre in the reinforcing matrixes has been tested (**Figure 6**) : the fibre has been immersed into a cement grout (water/cement ratio = 80) of 80 % for over a month. While alkali-resistant fibreglass sees its resistance diminish by half after just 5 days, the mechanical strength of quenched amorphous metallic fibre is slightly greater than that of the test fibre.

This result confirms the passivation of amorphous metallic fibres in alkaline environments, leading to upkeep, in fact an enhancement in mechanical performances.

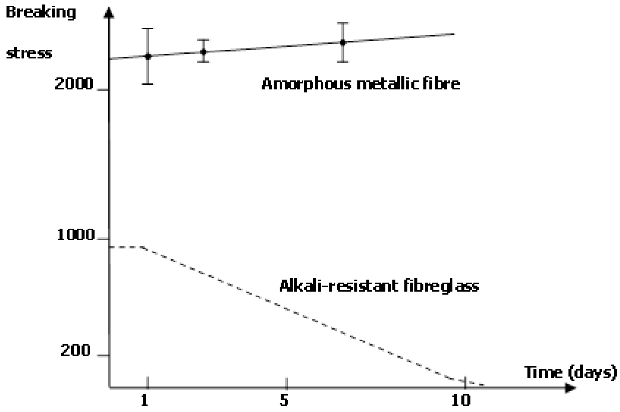

Figure 6.

Mechanical strength of the amorphous metallic fibre and alkali-resistant fibreglass after immersion into a cement grout at 80°C

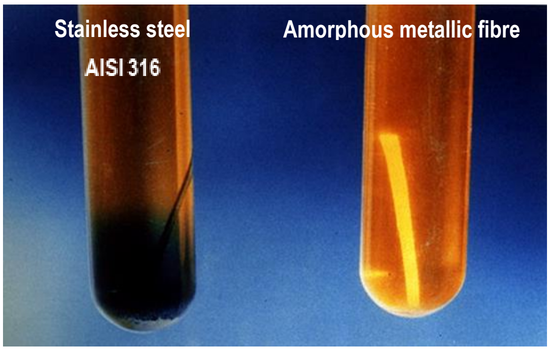

Figure 7.

Corrosion tests in 6 % $FeCl_3$ environment - Aspect of samples after 24 hours at 35°C

The resistance of amorphous metallic fibres to chloride ions has also been tested in HCl (0.1 N) and $FeCl_3$ (0.4 N) solutions for 24 hours at 35°C (ASTM G48-76-A standard) (**Figure 7**). Comparison has been made between amorphous metallic fibre and a steel wire AISI 316 (Type Z6 CND 17-11 or Z6 CND 17-12). From this test, it is observed that the solution containing stainless steel takes on a greenish tint. This change in colouring brings about a chemical reaction, in this case, through the transformation of Fe^{3+} ferrous ions into Fe^{2+} ferrous ions. Observation of the stainless steel wire with naked eyes and through microscope shows presence of significant pitting and on weighing, a loss in weight of 26 % is seen. In the case of amorphous metallic fibre, neither colouring of the element, nor pitting of fibre nor any loss in weight is noticed.

Thanks to their chemical composition and specific production process,
the amorphous metallic fibres show better corrosion resistance than stainless steel.

3. Corrosion resistance of fibre-reinforced concrete matrixes

To study the aging of fibre-reinforced concrete matrixes in various environments, mortar slabs reinforced with amorphous metallic fibres were placed in hot water at 50°C for 84 days. No change in flexural strength of the composite was noticed : 17 Mpa to J-0, 18 Mpa to J-84.

Subsequently, prismatic specimens (4 x 4 x 16 cm) made from a pure cement paste (E/C = 0.3) reinforced with amorphous metallic fibres 2.8 % by weight, have been immersed vertically half-way into saline solution at 50°C (58 g/l of NaCl and 5 g/l of $MgSO_4$, being double the concentration of sea water). The test was carried out over a period of 18 months with regular check of mechanical properties of the specimens (**Figure 8**).

In case of non-fibred samples, initially the flexural strength gets enhanced owing to the action of hot water (curing treatment). On the other hand, after one year, the resistance deteriorates, while in the case of samples reinforced with amorphous metallic fibres, it is noticed that their resistance increases. No trace of rust is observed on the amorphous metallic fibres while in specimens containing steel fibres immersed under similar conditions, significant traces of rust are observed.

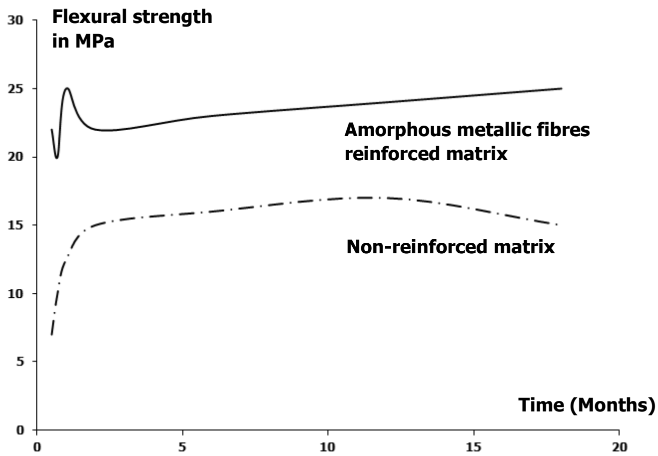

Figure 8.

Development of flexural strength of cement paste immersed in sea water

Finally, other tests involved exposing sections of concrete to dripping sulphuric acid pH4 or artificial salt spray at 35°C for 33 months :

Concrete sections exposed to salt spray at 35°C

Concrete containing steel wires
Aspect after 3 months

Concrete reinforced with FIBRAFLEX fibres
Aspect after 15 months

Hence, these tests help in demonstrating that FIBRAFLEX ensures safety of aspect : the fibre does not leave any traces of rust and helps to be free from the finish coat as is generally recommended for products which are sensitive to corrosion.

Besides these elements, the durability accrued from concrete reinforced with amorphous metals is also explained by the distinctiveness of mechanical reinforcement made through this special typology of fibres within the concrete matrix : due to their special characteristics, the amorphous metallic fibres bond to the matrix. Hence, the mechanical reinforcement made by these fibres within the matrix proves to be efficient right from time that the initial forces are applied and limits the manifestation of initial opening-up of cracks to the maximum. Especially, this limits the penetration of aggressive substances within the concrete matrix and its degradation.

➔ Limited attacks ➔ No corrosion ➔ No degradation ➔ Mechanical characteristics of concrete and reinforcement made by fibres preserved.

4. Conclusion concerning use of fibres

Corrosion resistance of amorphous metallic fibres is therefore absolutely remarkable : their passivation in aggressive environments allows greater durability of the reinforcement over a period of time.

Since their invention, these fibres have naturally found applications in the reinforcement of concrete and mortars which are subjected to corrosive attacks like :

- prefabrication concrete for nuclear specifications. Reinforced concrete for this type of fibres is guaranteed for a period of 300 years by the French Nuclear Authorities ;
- sealing mortars on highways = subjected to de-icing salts. Besides durability of reinforcement, the fibres help in delimiting the detrimental effects owing to fatigue and to the freezing / unfreezing cycles ;
- mortars used in repairs exposed to effluents in sewage systems ;
- concrete for facing panels where no traces of rust can be tolerated ;
- prefabrication concrete exposed to maritime atmosphere (artificial reefs) ;
- ...

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