Corrugated sheets for roofing and flat panels using new polypropylene fibers

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Composites in Construction 2005 – Third International Conference, Hamelin et al (eds) © 2005 ISBN xxxxx

Lyon, France, July 11 – 13, 2005

FIBER CEMENT: CORRUGATED SHEETS FOR ROOFING AND FLAT PANELS USING NEW POLYMERIC FIBERS.

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ABSTRACT: This present paper shows the reasons and the way used by Brasilit / Saint-Gobain Building Materials for the development of a new non-asbestos technology for fiber cement and the present status of this technology. This new technology is based on a new polymeric fiber of polypropylene having simultaneously higher tenacity and modulus, lower titer and elongation compared with commercial PP fibers in the market. Those mechanical properties combined with surface treatment giving good adhesion with cement paste and water dispersion have resulted in a reinforcement fiber able to support the requirements for roofing and panels applications made on Hatschek machines. Moreover, this new technology brings a very important mechanical property that is much lower in other fiber cement products: impact resistance.

1. INTRODUCTION

Fiber cement products have been widely produced and sold all around the world for about a century. Examples of those products are corrugated sheets for roofing, flat panels for siding, facades and partitions, water tanks, pipes for water and wastewater, etc. Flat and corrugated fiber cement products are often manufactured on Hatschek machines because of its high productivity capability. Initially both process and products were developed using a single formulation containing essentially 2 sources of raw materials: Portland cement and asbestos fibers.

In recent years, increasing pressure against asbestos use forced many manufactures to find alternative non respirable fibers. Such alternative fibers have to comply with the Hatschek process, be compatible with the high pH of the cement slurry, give products with mechanical strength and weather ability. They are also required to generate the lowest cost production increase when compared to former products.

A solution for asbestos replacement consists in the use of 2 types of fibers: cellulose pulp for process ability and alkali-resistant fibers when mechanical strength is needed. The fibers for mechanical strength are often made of PVA (polyvinyl alcohol). For historical reasons, PVA fibers are only produced in China and Japan. Transportation cost added to the fiber price gives a very expensive alternative solution for far countries.

In Brazil, Brasilit sells about 500 000 ton per year of fiber cement products. Therefore, the alternative fiber should also be available in high quantities immediately or rapidly. The use of PVA fibers was a technical but not an economical solution. Therefore another type of fiber had to be found. Several commercial fibers, mineral or organic, had been tested, no one provided all the required characteristics. Saint-Gobain finally developed an appropriate polypropylene (PP) fiber to be used in Hatschek process. This fiber is called Brasifil.

2. GENERAL ASPECTS OF NON-ASBESTOS FIBER CEMENT TECHNOLOGY

The original process for producing fiber cement articles was developed by Ludwig Hatschek at the end of the XIX century, based on the paper industry. The process adopted the name of his inventor. Since then, the Hatschek process has been improved to achieve higher productivity and better performance without changing the core technique: dewatering a diluted cement slurry in a rotating round sieve. Until today this process is widely used: about 85% of fiber cement sold around the world is produced according to the Hatschek process. At the same time composition of the products has also evolved, incorporating mineral filers, chemical admixtures and different types of cements in the original cement / fiber / water formulation.

Asbestos fibers play a double role in the process and in the product. Regarding process, asbestos fibers play a filter role in the retention of solid particles on the round sieve. Regarding the product, asbestos fibers insure a long term mechanical strength due to its high inherent strength and modulus and its chemical compatibility and perfect bonding with cement paste.

In asbestos-free products the filter role is normally played by a refined cellulose fiber. In applications where mechanical strength is required – as in corrugated sheets used for roofing - a second fiber is used to provide the mechanical reinforcement to the cementitious matrix. The most widely used fiber for this purpose is PVA (polyvinyl alcohol). Although this fiber exhibits the specified characteristics (mechanical strength and alkali resistance, dispersion in water, good adhesion with cement paste and rapid availability) it can not be considered as a solution because it fails in the economical aspect. PVA fiber production is very costly and transportation from Japan or China to Brazil is also very expensive. Products made with only cellulose fibers exist on the market but are autoclaved following the Hatschek process. Those products can be used in conditions where no high strength is required, and where saturated / dry cycles are less severe, for example in vertical panels. Certain-Teed – Saint-Gobain Building Materials in the USA produces and sells sidings using only cellulose fibers.

For Brasilit's roofing corrugated sheets, another reinforcement fiber had to be found.

3. DEVELOPMENT OF PP TECHNOLOGY AT BRASILIT

The development of a new-technology based on a PP fiber in Brazil started in 1997 with the reorganization of the Brasilit Development Center at São Paulo. The unique goal was to find an adequate alternative fiber to asbestos for Brasilit's products. The first industrial cellulose refiner was installed in Belém's plant in 1998, for initial cellulose trials. At that time, waste paper was thought to be a low cost solution for the filter process role. The solution finally adopted was the virgin cellulose. To boost the internal development, Brasilit acquired a PVA technology from SIL - Società Italiana de Lastre / Italy in 1999. SIL proposed a good solution with PVA fibers and a mix-design adapted to the climatic conditions of Europe, in which a significant amount of micro-silica was incorporated (and impacted the costs).

Adaptation for Brasilit's local market was performed in both reinforcement fibers and mix-design.
Between 1999 and 2001 Brasilit tested several different fibers available in the market and others slightly modified to suit its requirements:

- Acrylic fibers – failure in mechanical properties ;
- Polyamide fibers – failure in process ability and mechanical properties ;
- Cem-FIL AR glass fibers – good results with adequate matrix design, but not available in required quantities in the short term ;
- PP fibers – failure in mechanical properties in more demanding products.

Brasilit made a decision to convert all its 4 plants to PVA process in 2000. Conversion to a non-asbestos production consists mostly in adapting the process to work with a more diluted cement slurry. This represents a moderate investment in pipes and pumps. Investment to be able to produce a good refined cellulose has also to be made. The conversion was finished in 2002.

During this time the result of testing an alternative solution for PVA fibers showed that PP represented a good way.

Polypropylene resin is widely produced in the world. It is one of the most economical thermoplastic product and it is chemically inert. In Brazil, about 1 million of metric tones of PP resin were produced in 2001. Spinning PP resin is a physical treatment which is much easier than the chemical spinning of the PVA resin.

The Brazilian and French Development Centers of Saint-Gobain worked together in obtaining a high tenacity and high modulus PP fiber. A surface treatment allowing this non-polar material to adhere to cement and to disperse in water was required. Intensive industrial trials were made in 2001 and 2002 testing about 25 different versions of PP fiber and different matrix formulations, varying:

- Physical aspects: titer and length (6 to 12 mm) ;
- Mechanical properties: tenacity, modulus and elongation ;
- Activation surface agent and processing additives ;
- Processing parameters for fiber production ;
- Amount of pozzolan, aiming to reduce to zero.

Process parameters of Hatschek machine were to be defined to these new formulations.

Product performance was measured against product standards [1],[2],[3] where all characteristics for early and later age products had to be conform, except the freezing / thawing behavior. The best products were exposed under natural conditions and their behavior evolution was followed. Results allowed to take a decision in 2002 to invest in a plant for PP fiber production at Jacarei-São Paulo. The start-up of the plant was done one year later. Corrugated sheets using Brasifil started being produced in September 2003. Flat panels using Brasifil are in production since October 2004.

4. REINFORCEMENT FIBERS AND THEIR PROPERTIES

The polypropylene fiber named Brasifil and its process production were developed by Saint Gobain in Brazil. Its high performance is obtained thanks to a balance of properties such as high tenacity, low titer, moderate elongation and high modulus associated to a specific surface treatment during processing (Table 1). This chemical treatment improves both dispersion ability and affinity with the cement paste, changing the hydrophobic characteristics of PP. Brasifil is a non respirable fiber.

Figure 1 presents the spinning process of Brasilit plant for producing polypropylene fibers.

Figure 1 – Spinning and drawing processes for producing PP Brasifil

Table 1 – Properties of polymeric reinforcement PP fiber developed by Saint Gobain in comparison with asbestos and commercial polymeric reinforcement fiber PVA.

Characteristics		**Chrysotile Asbestos**	**PVA**	**PP Brasifil**
Specific Gravity (g/cm3)		2,55	1,30	0,91
Cut Length (mm)		0 – 5	6	10
Diameter (µm)		0,5	14	12
Linear Density (dtex – g/10000m)		n.d.	2	1
Dry Tenacity	cN/dtex	n.d.	12 - 14	9,3
	Mpa	3100	1600 - 1800	840
Elongation at rupture (%)		0,5	7	21
Young's Modulus	cN/dtex	n.d.	250 - 280	90
	Gpa	160	32 - 36	8
Alkaline Resistance		Excellent	Excellent	Excellent
Cement Affinity		Excellent	Good	Good
Fibrillation		Present	Absent	Absent

Figure 2 presents micrographs of asbestos showing a large amount of filaments of varying size occurring as natural mineral.

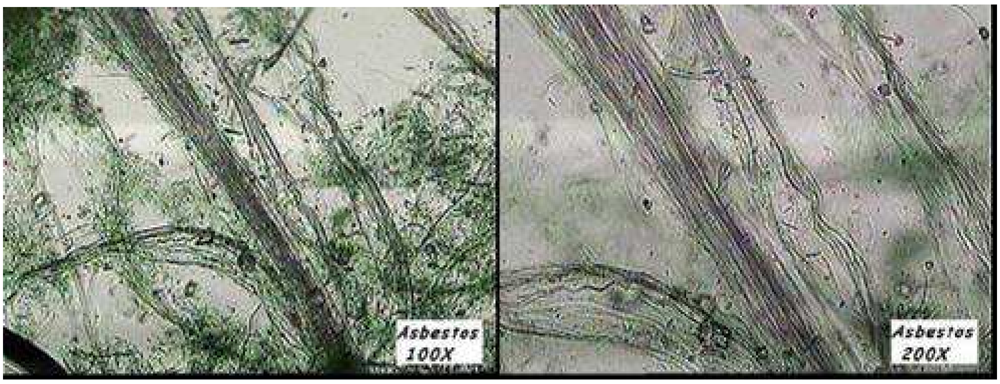

Figure 2 – Micrographs of asbestos (magnification of 100X and 200X)

Figure 3 presents micrographs of commercial PVA fibers having an average of 14 µm of diameter and 6 mm length.

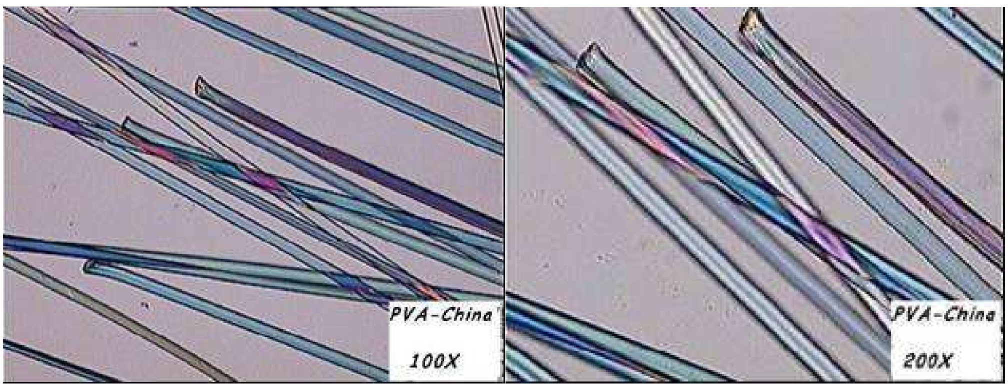

Figure 3 – Micrographs of commercial PVA (magnification of 100X and 200X)

Figure 4 presents micrographs of PP Brasifil which has 12 µm diameter and 10 mm length.

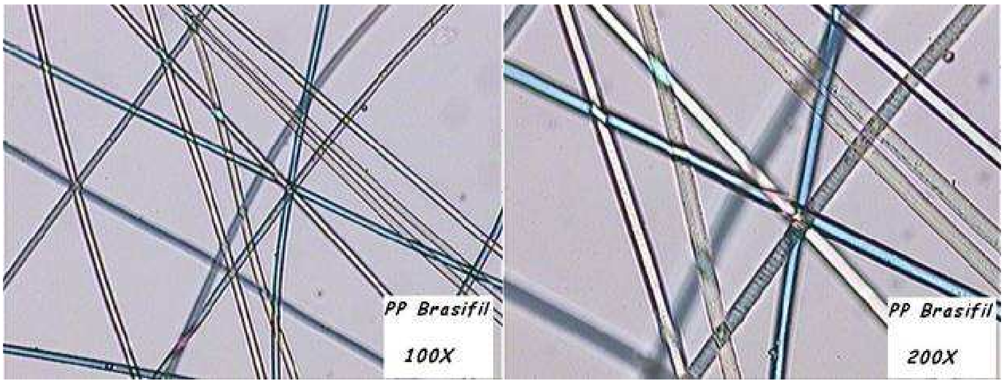

Figure 4 – Micrographs of PP Brasifil (magnification of 100X and 200X)

5. NON-ASBESTOS CORRUGATED SHEETS

In 2002, Brasilit started to produce and commercialize non-asbestos fiber cement products, mainly P3 et P7 corrugated sheets, using PVA fibers. Moving from PVA to PP fiber did not require equipment modifications, only some process adjustments. Today, all Brasilit corrugated sheets are made with Brasifil PP fiber.

5.1 Breaking Load

Breaking Load values are obtained following ISO 9933 [3] method. Figure 5 and Table 6 show the difference in the breaking load in corrugated sheets for those 3 fibers. It can be noticed that despite the difference in fibers properties described in Table 1, the impact in the product strength is very low. The reason for that behavior is to be found in the high porosity of the cement matrix (about 30 % of water absorption), typical value in fiber-cement products. That high porosity limits the utilization by the matrix of all the intrinsic fiber properties.

5.2 Deformation Behavior of PP Corrugated Sheets

The deformation curves of the breaking load test demonstrate an interesting behavior brought by the Brasifil PP fiber – See Figure 5. The quality and quantity of the sizing agent used for the surface treatment of the fibers during the spinning and drawing production stages, allow a controlled adhesion to the cementitious matrix. After the pick of maximum load, the energy is absorbed for debonding the PP fibers out the matrix. With PVA or asbestos, the bonding is too high and fibers break, limitating the amount of energy absorbed.

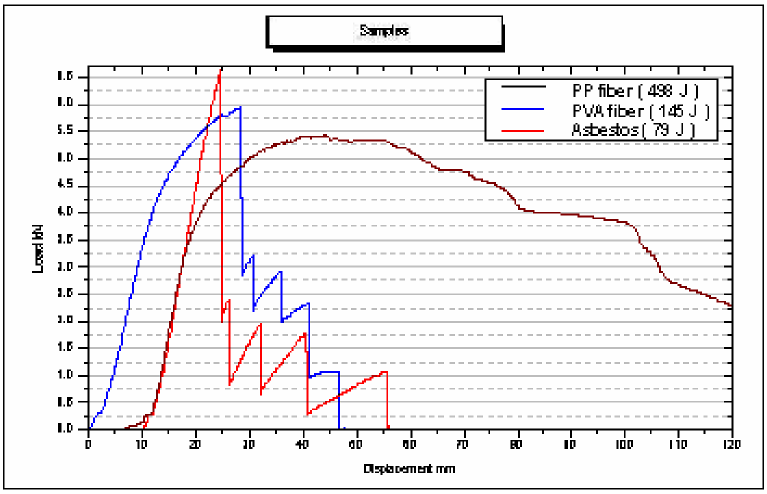

Figure 5 – Comparison curves of breaking load of corrugated sheets with PP Brasifil, PVA and asbestos after conditioning at room temperature (according to EN 494:1994[1]). In parentheses, the calculated total energy to break (in Joules).

By integrating the area below the curve the total energy which can be dissipated during an impact is calculated. (See Figure 6). As a consequence, Brasifil fiber cement products have a better handling and less break during transportation when compared with asbestos or PVA.

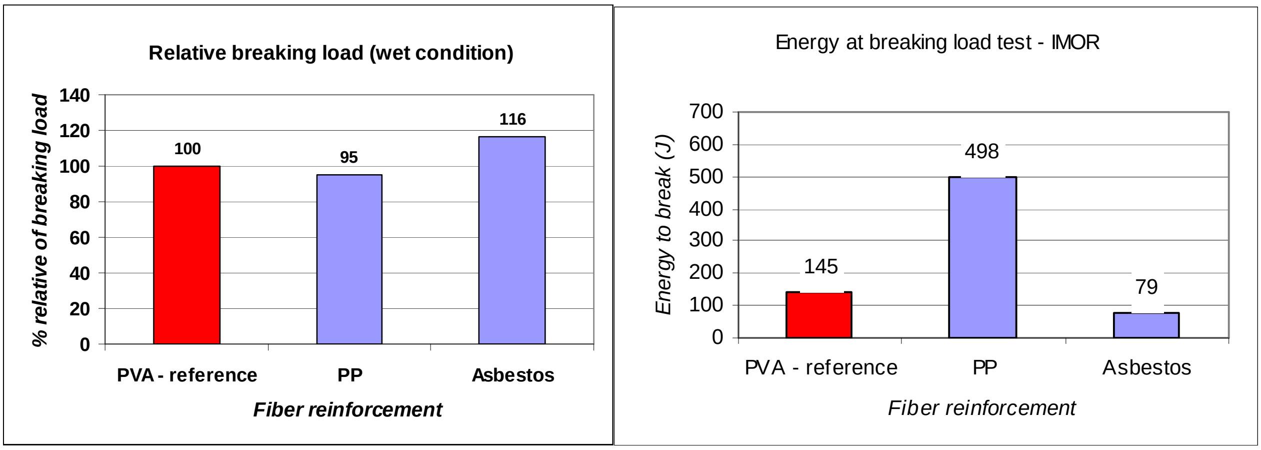

Figure 6 – Example representative of relative breaking load under wet condition and the IMOR-energy to break of PP and asbestos corrugated sheets in reference to PVA.

5.3 Impact Resistance Test

The practical consequence of the higher energy absorption of Brasifil PP fiber cement corrugated sheets can be clearly observed during a 600 J impact resistance test shown in Figures 7 and 8 (test in accordance to NF P 33-303-1 [2]).

Figure 7 – Impact resistance test (600 J) of corrugated sheet P7 – 6 mm using Brasifil.

Figure 8 – Impact resistance test (600 J) of asbestos corrugated sheet P7 – 6mm.

As it is shown in this test, a non-asbestos corrugated sheet with security requirements could be obtained using Brasifil PP fibers. Products made with asbestos or PVA fail in this test. This performance does not change after the accelerated ageing tests made in accordance to ISO 9933.

5.4 Other Properties

Brasifil PP fiber cement products comply with all other requirements stated in ISO 9933:1995 standards [3], as impermeability, heat / rain resistance, etc. and including accelerated ageing tests. Freeze / thawing is not required for Brazilian climate.

Table 2 shows the data of accelerated ageing tests performed on corrugated sheets in accordance to standards [1] and [3]. Those ageing tests refer to warm water and immersion / dry cycles. L is required to be higher than 0,7. Besides the standard procedures, Brasilit follows the behavior of natural exposed roofing.

Table 2 – Data from ageing tests performed on PP corrugated sheets.

	L	Reference standard
Warm water 60ºC x 56 days	1,02 ± 0,07	ISO 9933:1995 [3]
Immersion and heat 60º x 50 cycles	1,15 ± 0,10	EN 494:1994 [1]

For each lot tested, L is defined as: $L = (M_2\text{-}0{,}58\ s_2)/(M_1+0{,}58\ s_1)$
Where,

M_1 and s_1 are respectively the average and standard deviation of load of rupture of reference lot at 95% of confidence level.

M_2 and s_2 are respectively the average and standard deviation of load of rupture after immersion in warm water or immersion and heat tests.

These results of ageing tests are compatible with data published in a recent work by LHONEUX et al. [4] performing ageing tests and natural weathering in Latin America and Europe.

6. NON-ASBESTOS FLAT PANELS

Similarly to corrugated sheets, Brasilit has recently launched a Brasifil PP fiber cement panel for applications based on “dry-wall” system in accordance to ISO 8336 standard [5] (Figure 9), available in 4, 6, 8 and 10 mm. Here again, Brasifil PP fiber could advantageously replace previous solutions done with PVA fibers.

Figure 9 – Example of fiber-cement flat panels application.

7. CONCLUSION

Manufacturing non-asbestos fiber cement products at the lowest cost production was the first driving force on Saint-Gobain decision to develop and produce a new PP reinforcement fiber.

Since 2002 when conversion lines were completed, Brasilit has already commercialized over 1 M ton of non-asbestos products, from which about half were produced with Brasifil PP technology.

With Brasifil PP fiber, the production cost of fiber cement sheets is about 12% above the production cost with asbestos. Cost production with PVA was more than 35 % above asbestos. Productivity on the Hatschek machines is similar to asbestos products, and improvements in processing and new developments on raw materials and formulation are contributing to cost reduction.

This new fiber cement technology is a real possibility in the fiber cement world, and represents a good opportunity for companies looking for competitive asbestos-free products. It is already recognized internationally. A recent know-how transfer between Brasilit and Everest Industries, a fiber cement producer in India, has been signed.

8. REFERENCES

[1] European Norm EN 494:1994 – *Plaques profilées en fibres-ciment et accessoires pour couvertures.*

[2] Norme française NF P 33-303-1 :1997 – *Plaques profilées en fibre-ciment – Résistance à la traversée d'un corps mou de grandes dimensions.*

[3] International standard ISO 9933:1995 – Products in fiber-reinforced cement – *Long corrugated or asymmetrical section sheets and fittings for roofing and cladding.*

[4] Lhoneux, B.de;Alderweireldt, L.; Albertini, E.; Capot, Ph.; Honorio, A.; Kalbskopf, R.and Lopez, H. *Durability of polymer fibers in air-cured cement-cement roofing products. The Ninth International Conference on Inorganic-Bonded Composite Materials Proceeding – Vancouver/October, 2004*

[5] International standard ISO 8336:1993 – *Fiber cement flat sheets*.