ASBESTOS-FREE TECHNOLOGY WITH NEW HIGH TENACITY PP – POLYPROPYLENE FIBERS IN AIR-CURED HATSCHEK PROCESS.

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ABSTRACT

After almost 70 years of experience in the fiber-cement production in Brazil, Saint-Gobain Brasilit started the non-asbestos production using PVA-Polyvinyl alcohol fiber technology in 2002.

Due to PVA costs and availability problems, efforts were done to develop a local high tenacity PP – Polypropylene fiber, with improved frictional interface and better dispersion and affinity to Portland Cement matrix.

In the last 5 years, more than 1,6 millions tons of asbestos-free corrugated and flat sheets have been produced and commercialized representing about 200 millions of m2.

This paper reviews the alternative fibers for replacing asbestos and the reinforcing model in cement based products. It also presents the Brasilit high tenacity polypropylene fibers properties, its manufacturing process and its mechanical performance and improved impact resistance behavior comparing to fiber-cement products available in the Brazilian market.

KEYWORDS:

Fiber-cement, polypropylene fiber, high tenacity, impact resistance.

INTRODUCTION

Fiber-cement asbestos based products had been widely used in the world due to their versatility as corrugated and flat roofing materials, cladding panels and water containers presented in large number of building and agriculture applications. In the early of 1980's asbestos based materials started to be replaced by alternative non-asbestos materials.

Actually around the world there are two production routes of non-asbestos materials using Hatschek technology:

- Steam cured products reinforced by cellulose fibers (autoclaved products), mainly for external cladding and internal partitioning and ceiling; and
- Air cured products reinforced by alkali-resistant synthetic fibers combined refined cellulose fibers, usually for corrugated sheets.

Examples of synthetic materials are polyvinylalcohol fibers (PVA), alkali-resistance glass fibers (AR-glass), polyacrylonitrile fibers (PAN) and, more recently, polypropylene fibers (PP).

Among these fibers, high tenacity PVA fibers were the first to be used on large scale and industrial bases, considering its intrinsic properties: high tensile strength, high modulus, and low elongation, high durability in alkaline matrix, hydrophilic behavior, good dispersion in water, and good bonding with cement paste. The costs of PVA fibers had however limited its use in Brazil.

On the other hand, polypropylene (PP) resin is relatively less expensive and worldwide available, used in a large number of applications ranging from food packing to chirurgical masks. It can be processed by traditional melt spinning technologies and it is chemically inert and resistant to cement paste. To be used as a cheaper substitute for asbestos, PP fibers needed to have changed its original hydrophobic character, improve its tenacity, dispersion in water and interfacial bonding to Portland cement.

After intense studies, Saint-Gobain Brasilit has developed and started the production of its high tenacity PP fiber for asbestos replacement (named Brasifil) in 2003. With this successful technology Saint-Gobain Brasilit has already produced and commercialized more than 1.6 millions ton of asbestos-free corrugated and flat panels representing about 200 millions of square meters.

FIBRE-CEMENT HATSCHEK TECHNOLOGY

The original process for fiber-cement manufacturing was developed by Ludwig Hatschek at the end of 19^{th} Century based on the paper industry which process has received the inventor's name. Since then, Hatschek process has been subjected to constant improvements to achieve high output and better performance without affecting its basic principle: filtering a dilute suspension of cement on a rotating cylinder sieve.

Figure 1 – General view of Hatschek machine, pressing roll, cutting system and corrugating process.

The thin layer obtained by filtration is transferred and accumulated in cylindrical presses, until the desired thickness. Later the green sheet is cut and conformed as a corrugated sheet or flat panel.

Even today, this process is widely used: almost 85% of fiber-cement products sold in the World are produced by Hatschek process. On the other hand, composition has experienced new developments by incorporating mineral and synthetic fibers, chemical additives and cements with new characteristics.

FIBER REINFORCEMENT MODELINGS

As presented in Lhoneux et al, 2002, modeling for reinforcement of fiber-cement composites covers several factors classified in groups such as fiber and matrix properties, interaction of fiber-matrix parameters and fiber volume fraction.

In addition to those parameters, modelings also discuss on geometric factors related to flexural stresses in inclined fibers (Struke and Majumdar, 1976, Katz and Bentur, 1996 and Motta, et al, 2003).

In order to obtain better results on the existing synthetic fiber for reinforcement apart from all those parameters, frictional bond is key factor to study which can be modified by improving geometric factors (diameter/length ratio) and bonding interaction of fiber-matrix.

ALTERNATIVE SYNTHETIC FIBERS

Following the worldwide tendency for replacing asbestos, manufactures started to look for new alternatives for fiber reinforcement which comply with Hatschek machines and provides good performance and high functional durability products.

In addition to long term durability, compatibility to Portland cement matrix, process ability, availability and cost, alternative fibers for reinforcement must have high mechanical properties. High tenacity, high modulus and reduced elongation at rupture are considered key attributes.

The graph at figure 2 shows the mechanical characteristics of some commercial alternative fibers for reinforcement and their main determinant factors. It was confirmed that high tenacity PVA modulus presents values around 15 MPa for the evaluation range differently than values stated by some producers (Houang, 2001 and Motta, 2003).

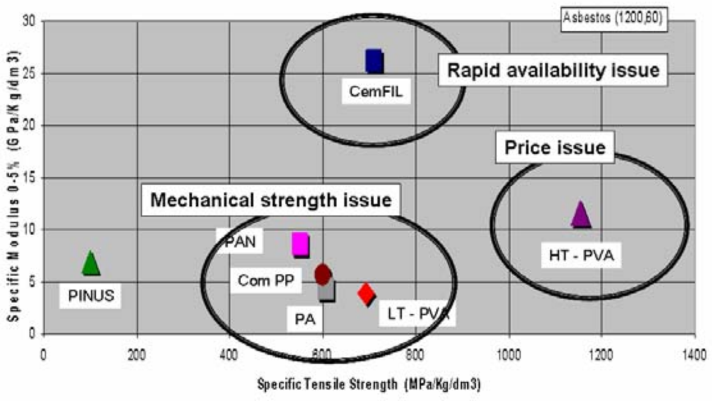

Figure 2 – Characteristics of commercial alternative fibers available in the market with main key factors. (Note: Pinus = Cellulose; PAN = Poly Acrylo-nytrile; Com PP = Regular Polypropylene; PA = Polyamide; LT-PVA= Low tenacity Polyvinylalcohol; HT-PVA= High tenacity Polyvinylalcohol; CemFIL= alkali-resistant glass fiber). Modulus was determined considering the range of elongation curve between 0 to 5%. Graph units were obtained by dividing the represented property by respective material specific density.

The figure 3 shows the position of the new high tenacity PP fiber “Brasifil” in reference to other alternative fibers for reinforcement.

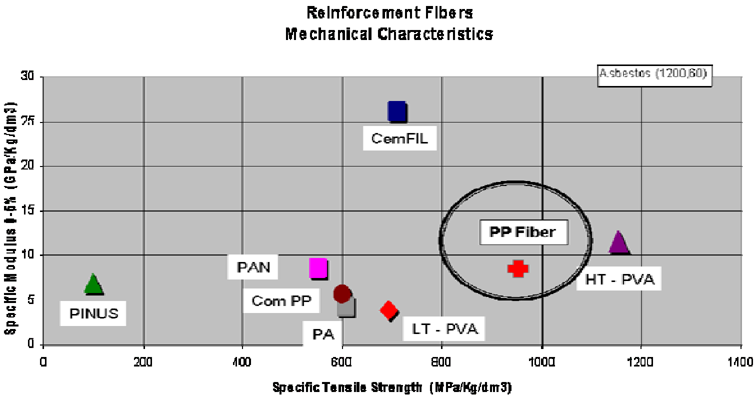

Figure 4 - New Brasifil PP fiber in comparison to commercial alternative fibers. (From Houang, 2001)

DEVELOPMENT OF NON-ASBESTOS TECHNOLOGY AT BRASILIT

In 1997, a research project for replacement of asbestos was defined starting from sourcing of alternatives raw materials to project and installation of machines for the new process. A cellulose refining plant was also included. This process has ended by the conversion of all Brasilit plants for non-asbestos technology.

The table 1 presents the main steps carried out by Brasilit for the non-asbestos technology adoption.

Table 1 – Main facts of non-asbestos conversion lines at Brasilit.

Period	Event
1997-98	Reorganization of the Brasilit Research and Development Center. First trials at Brasilit-Belém/PA plant testing different materials such as: waste paper, virgin cellulose, acrylic and polyamide fibers and alkali-resistant glass fibers (Cem-fil Vetrotex).
1998-99	Studies on increasing long-term durability of Cem-fil in cement matrix using metakaolin. Acquisition from SIL-Societá Italiana de Lastre the PVA/silica fume technology for corrugated sheets.
1999-2000	Adjustments of SIL technology to Brazilian sources of raw materials and process parameters. Conversion of first production line for non-asbestos at Brasilit Belém/PA plant to produce PVA products. PVA fibers imported from Japan and China.
2001	Launch of non-asbestos PVA based products in the Brazilian market.
2002	Completed conversion of all four Brasilit Plant (7 production lines) Decision taken for installing a PP fiber plant in Brazil. Research and development together with R & D team of CRM – Centre de Recherche de Matériaux of Saint-Gobain/France.
2003	Start up of polypropylene fiber plant at Jacarei/SP. Development of non-asbestos air-cured flat panels PP reinforced (new product not autoclaved without grounded silica - patented by Saint-Gobain)
2003-04	Conversion production from PVA to PP reinforced products. End of the industrial joint-venture Eterbras agreement.
2005-06	Agreement for PP technology transference to Everest Company / India Development of anti-crack PP fiber for concrete reinforcement in US market by Vetrotex Reinforcement.
Present	Achievement of good quality and productivity levels with PP fibers. Further decrease PP products cost is still the major aim (PVA/asbestos ~40% higher; PP/asbestos ~15-20% higher).

IMPROVEMENT ON INTERFACIAL SURFACE OF BRASILIT HIGH TENACITY PP

After converting all production lines to run with non-asbestos technology in 2002 and facing high cost to import PVA fibers, Brasilit has decided to develop a new alternative fiber for reinforcement. At that time, polypropylene has presented as good alternative resin produced worldwide in addition to the fact of being chemically inert. In Brazil, the actual production capacity is about 1.6 Mton/year and is foresee to increase by 20% by the year of 2010.

Some studies mention that poor bonding of ordinary PP fibers, even those with relatively high tenacity values, are due to their low surface energy ("hydrophobic character") and their low roughness (Lhoneux et al, 2004).

For this reason, a development study was established to improve the chemical interfacial bonding of Brasilit PP fiber. The large influence of the surface treatment on the strength and tenacity of the fiber-cement composites are evidenced by pull-out tests carried out at Saint-Gobain Recherche Center.

More than 25 different versions of PP fibers were investigated. Specimens were cut in flat parts of wave sides of industrial corrugated sheets and notches were made for controlling the pull-out tests (Figure 4).

In the figure 4 presents "pull-out" testing **for** commercial PP and PVA fibers in comparison to first and last generation of surface treated PP developed by Saint-Gobain at CRM-Centre de Recherche de Matériaux/France.

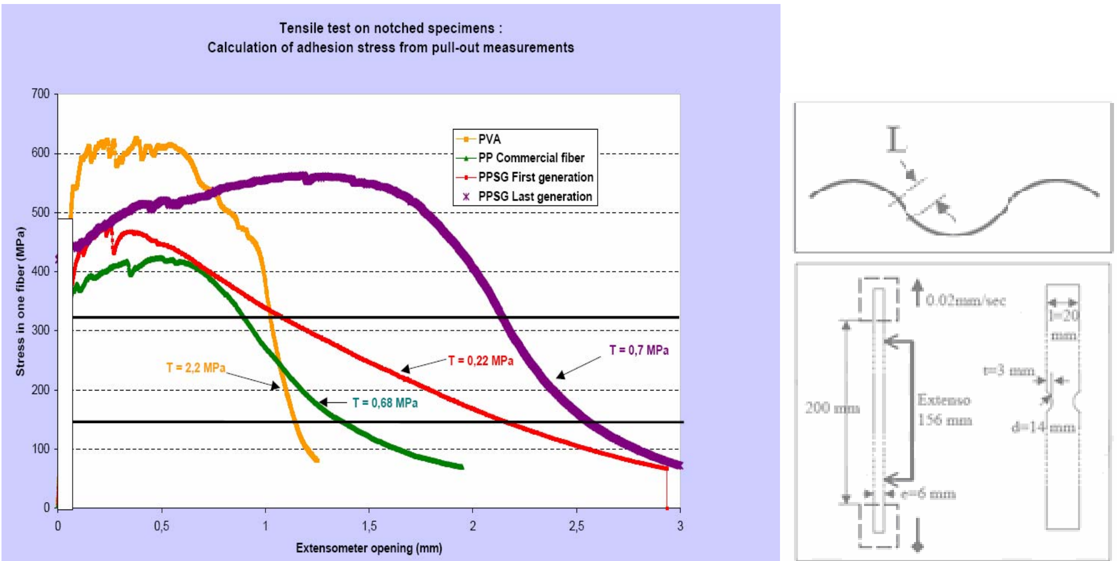

Figure 4 – Testing procedure diagram and comparison between commercial PP and PVA to surface treated PP's fiber developed by Saint-Gobain—CRM / Brasilit. (From Morlat, 2001)

The interfacial frictional bonding increased from 0.22 MPa in the first non treated PP fibers to approximately 0.7MPa in the last generation surface treated PP fibers produced by Brasilit. Those results are in accordance with the values presented in the literature (Lhoneux et al., 2004), ranging from 0,22 to non-treated PP fibers to 0.7-1.5 MPa after adding functional groups able to chemically improve the binding with cement (coating and copolymers) and/or increasing the roughness of the surface of the fibers with fillers or coatings.

BRASILIT PP FIBER PRODUCTION PROCESS

Brasilit PP fiber plant / Jacarei-SP was specially designed to produce high tenacity PP yarns able to be applied in replacement of asbestos in Portland cement matrix.

The production process starts from the extrusion of PP resin specially developed to achieve high tenacity in thin monofilaments. Geometry, spinning holes and cooling rates were considered in the conception of spinning melting heads to obtain filaments with high tenacity within narrow dispersion of properties.

To explore the maximum of each property, the process for Brasilit PP fiber was designed in two steps: spinning / bobbin and drawing/cut stages. The figures 5 and 6 illustrate those two stages.

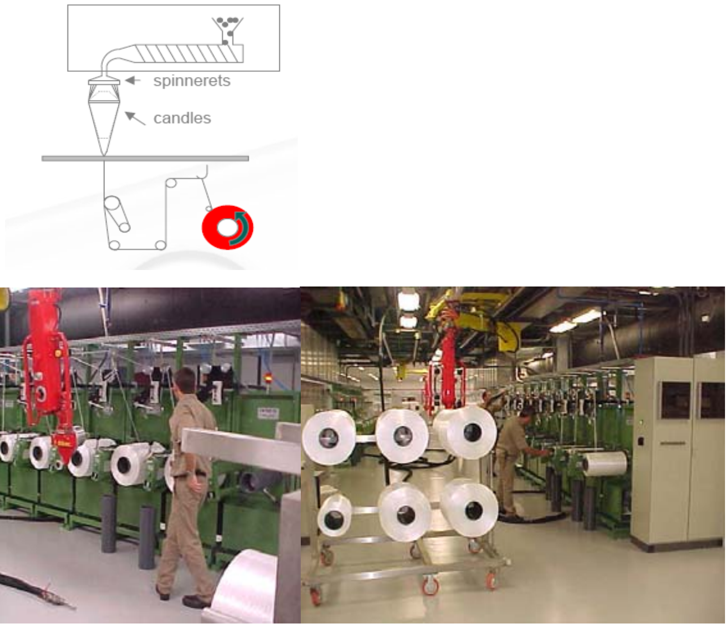

Figure 5 – Spinning and bobbin stage

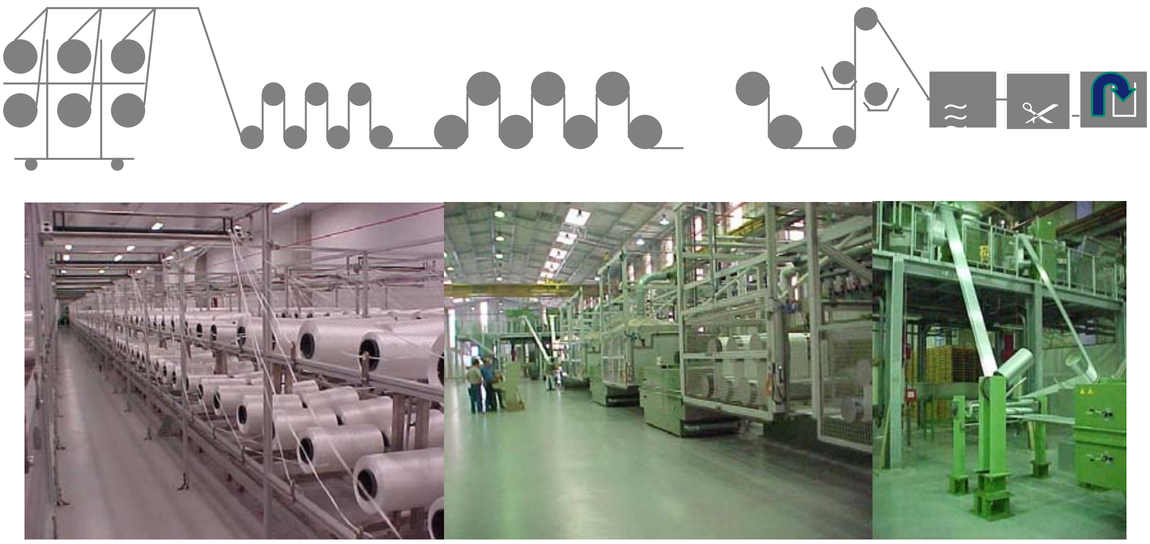

Figure 6 - Drawing/Spin finishing/Cutting stage

In the table 2 is presented the characteristics of filaments after each stage of the process

Table 2 – General characteristics of filaments after each stage of the process.

Characteristics	*After Spinning*	*After Drawing (typical values)*
Young's Modulus at 0-5% (GPa)	----	6
Dry Tenacity (MPa)	150	850
Diameter (micron)	27	10 to12
Elongation at Rupture (%)	520	21
Fiber length (mm)	----	6,10,12, 18
Production capacity (ton/year)	----	9,500

Note: Other fiber lengths are available under request.

QUALITY CONTROL AT JACAREÍ PP PLANT

Figures 7 and 8 illustrate the low dispersion and excellence in quality level of PP fiber produced at Brasilit Jacarei plant.

Year 2005	Diameter (Title)		Tenacity	
	dtex	microns	CN/dtex	MPa
Jan	1,02	11,9	9,27	844
Feb	1,00	11,8	9,34	850
Mar	1,00	11,8	9,30	846
Apr	0,99	11,8	9,28	844
May	1,01	11,9	9,35	851
Jun	0,99	11,8	9,30	846
Jul	1,02	11,9	9,38	854
Aug	1,02	11,9	9,36	852
Sep	1,02	11,9	9,31	847
Oct	0,99	11,8	9,30	846
Nov	0,98	11,7	9,43	858
Dec	0,98	11,7	9,40	855
Avg 2005	1,00	11,84	9,34	849
Std Dev	0,02	0,09	0,05	4,57

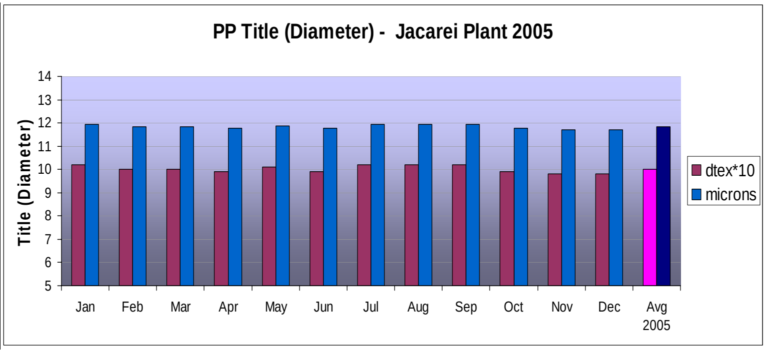

Figure 7 – Quality data for dimensional and mechanical properties.

Year 2005	E-Modulus - 0,4%		Elongation %
	(CN/dtex)/ 10	GPa	
Jan	9,682	8,8	21,50
Feb	9,835	8,9	21,61
Mar	9,802	8,9	21,40
Apr	9,560	8,7	21,52
May	9,641	8,8	21,05
Jun	9,734	8,9	20,77
Jul	9,886	9,0	21,21
Aug	9,960	9,1	20,02
Sep	9,741	8,9	20,71
Oct	9,762	8,9	20,10
Nov	10,800	9,8	20,58
Dec	11,151	10,1	20,50
Avg 2005	9,963	9,1	20,91
Std Dev	0,491	0,4	0,55

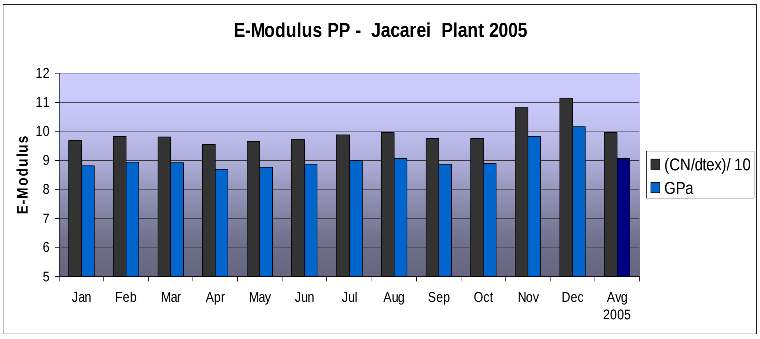

Figure 8 – Quality data for mechanical properties.

COMPARISON BETWEEN ASBESTOS, PVA AND PP BRASILIT FIBERS

The main properties of high tenacity PP fiber developed by Saint Gobain in comparison with asbestos chrysotile and commercial PVA fiber are presented in Table 3.

Table 3 - Properties of polymeric reinforcement PP fiber developed by Saint Gobain in comparison with asbestos and commercial polymeric PVA reinforcement fiber.

Characteristics		Chrysotile Asbestos	PVA	PP Brasilit
Specific Gravity (g/cc)		2.55	1.3	0.91
Length (mm)		0 - 5	6	10
Diameter (microns)		0,5	14	12
Linear Density (dtex - g/10000m)		n.d.	2	1
Dry Tenacity	CN/dtex	n.d.	12 to 14	9,3
	MPa	3100	1600 - 1800	850
Elongation at Rupture (%)		0,5	7	21
Young's Modulus (0 - 1%)	CN/dtex	n.d.	250 - 280	90
	GPa	160	32 - 36	6
Alkaline Resistance		Excellent	Excellent	Excellent
Cement Affinity		Excellent	Good	Good
Fibrillation		Present	Absent	Absent

Figure 9 presents micrographs of asbestos showing a large amount of filaments of varying size occurring as natural mineral.

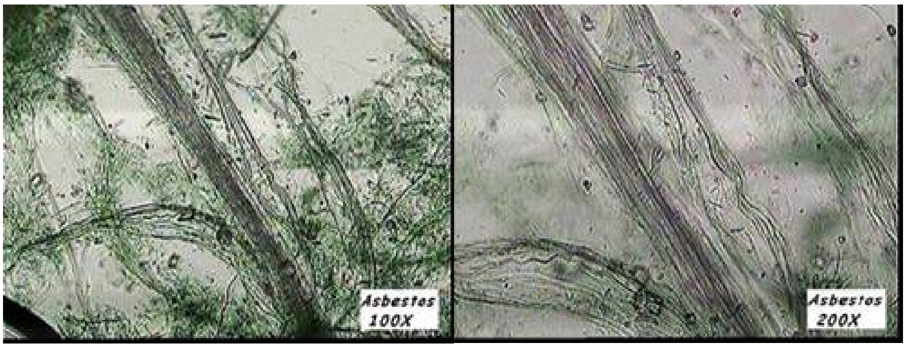

Figure 9 – Micrographs of asbestos (magnification of 100X and 200X)

Figure 10 presents micrographs of commercial PVA fibers having an average of 14 µm of diameter and 6 mm length.

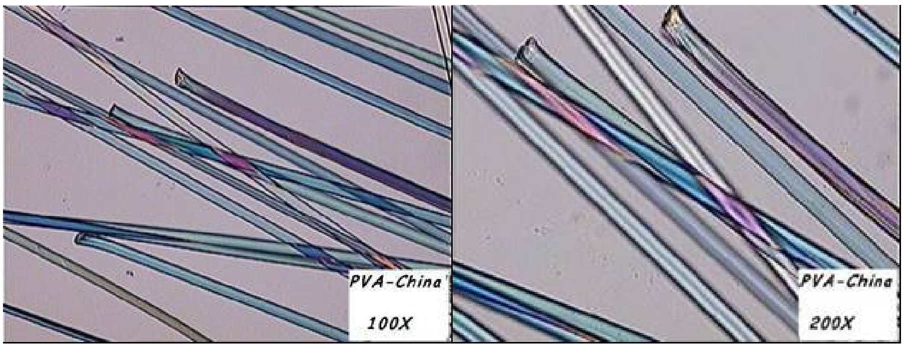

Figure 10 – Micrographs of commercial PVA (magnification of 100X and 200X)

Figure 11 presents micrographs of PP Brasifil which has 12 µm diameter and 10 mm length.

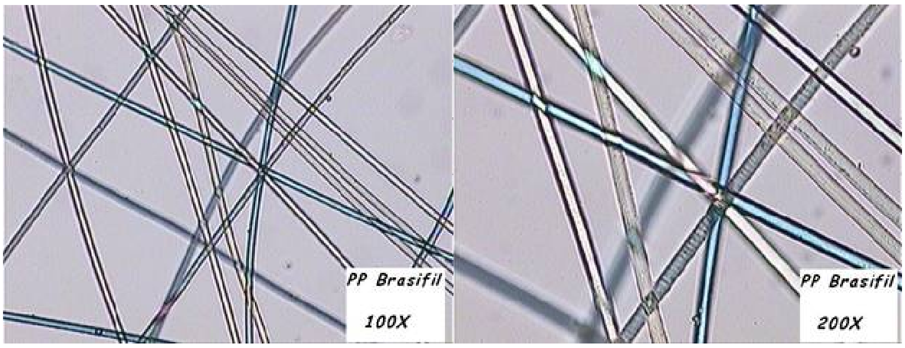

Figure 11 – Micrographs of PP Brasifil (magnification of 100X and 200X)

MECHANICAL BEHAVIOR OF CORRUGATED SHEETS WITH PP BRASIFIL, PVA AND ASBESTOS

The deformation curves of the breaking load test demonstrate an interesting behavior brought by the Brasifil PP fiber – See Figure 12. The quality and quantity of the spin 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.

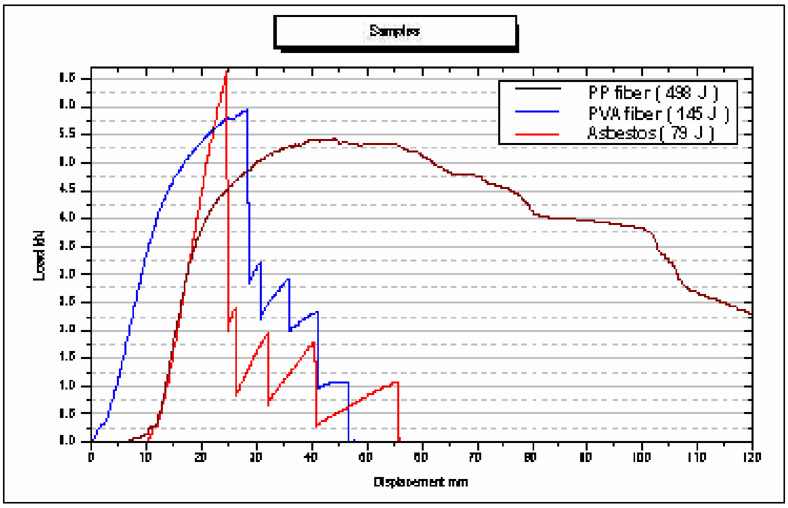

Figure 12 – Comparison curves of breaking load of corrugated sheets with PP Brasifil, PVA and asbestos after conditioning at room temperature (according to EN 494:1994). In parentheses, the calculated total energy to break (in Joules).

By integrating the area below the curve the total energy which can be dissipated during an impact is calculated (see Figure 13). As a consequence, Brasifil fiber cement products have a better handling and less break during transportation when compared with asbestos or PVA.

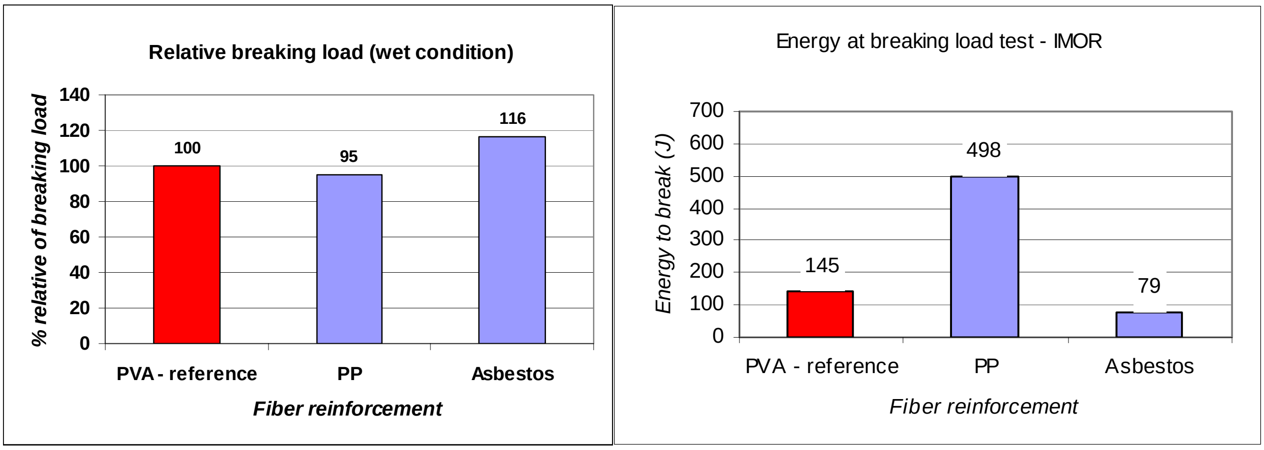

Figure 13 – Example representative of relative breaking load under wet condition and the IMOR-energy to break of PP and asbestos corrugated sheets in reference to PVA.

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 14 and 15 (test in accordance to NF P 33-303-1).

Figure 14 – Impact resistance test (600 J) of corrugated sheet P7 – 6 mm using Brasifil.

Figure 15 – 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 9933:1995.

Figure 16 presents a comparison between PP-reinforced and asbestos products at IMOR testing. At early ages when the matrix is still hardening IMOR has a maximum value greater than asbestos due to plastic deformation. A drop on IMOR curve was observed with the evolution of the hydration process followed by a new increase related to the strengthening of the matrix. Even after dropping in IMOR, PP-reinforced product has higher values comparing to asbestos products.

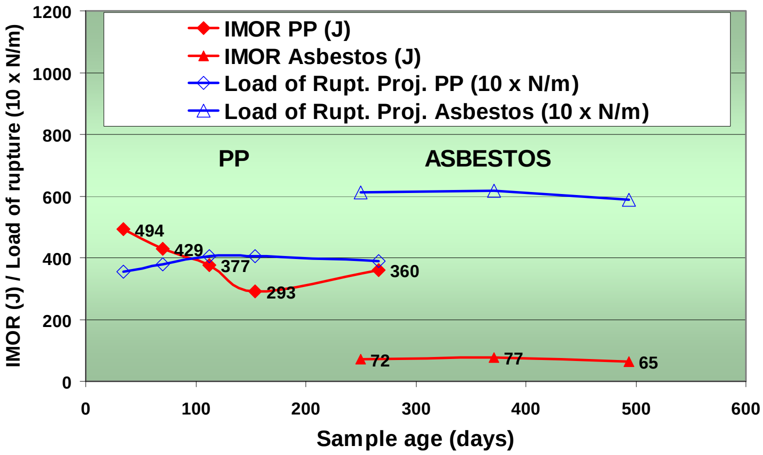

Figure 16 – PP-reinforced and asbestos product comparison of IMOR behavior at early ages

PP REINFORCED FIBER-CEMENT PRODUCTS AT BRASILIT

Actually, all corrugated sheets and fitting products for roofing produced by Brasilit are made with PP fiber in accordance with ISO 9933:1995 and Brazilian standard and the most common products are P3, P6 and P7 profiles as presented in the table 4.

Table 4 – Geometric Properties of Brasilit PP Products

Profile		Height of Corrugation (mm)	Corrugation Pitch (mm)	Thickness (mm)	Classification ISO / NBR
①	P3	24	75	4	A1
②	P6	39	150	4	B3
③		39	150	5	B4
④	P7	51	177	5	C6
⑤		51	177	6	C7
⑥		51	177	8	C8

Table 5 presents the specification for non-asbestos corrugated sheets in reference to profiles according to NBR 15210:2005.

Table 6 presents the most common dimensions of non-asbestos corrugated sheets available in the Brazilian market.

Table 5 – Minimum saturated breaking load per meter width according to category and class from NBR 15210:2005

Category (h=height of profile)	*Minimum saturated breaking load N/m*									
	Class									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
A (15 ≤ h ≤ 25 mm)	600 ①	800	1000	1400						
B (25 < h ≤ 40 mm)		800	1000 ②	1400 ③	2000	2500	3300			
C (40 < h ≤ 60 mm)						2500 ④	3300 ⑤	4250 ⑥		
D (60 < h ≤ 150 mm)								4250	5600	7400

Table 6 – Dimensions of Brasilit Products

Profile	*Product dimensions*								
	Thickness (mm)	*Width (mm)*	*Length (mm)*						
			1220	*1530*	*1830*	*2130*	*2440*	*3050*	*3660*
P3	4	500	✓			✓	✓		
P6	4	500	✓		✓	✓	✓		
	5	500	✓		✓		✓		
P7	5	920 / 1100	✓	✓	✓	✓	✓		
	6	920 / 1100	✓	✓	✓	✓	✓	✓	✓
	8	920 / 1100	✓	✓	✓	✓	✓	✓	✓

AGEING TESTS PERFORMED ON PP PRODUCTS

Brasifil PP fiber-cement products comply with all other requirements stated in NBR 15210 which is equivalent to ISO 9933:1995 standards concerning water permeability resistance, heat / rain resistance, etc. and including accelerated ageing tests. Freeze / thawing resistance is not required for Brazilian climate.

Table 7 shows the data of accelerated ageing tests performed on corrugated sheets in accordance to above standards. 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 monitors the behavior of some natural exposed roofing.

Table7 – 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 and NBR 15210:2005- part 2
Immersion and heat 60º x 50 cycles	1.15 ± 0.10	EN 494:1994

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 comply with information published in a recent work (Lhoneux, et al., 2004) which has performed ageing tests and natural weathering in Europe and Latin America where PP fibers were evaluated after 1000 cycles wetting/drying in a CO2 rich environment.

It is believed that accelerated ageing tests in CO2 rich environment results in better correlation to natural weathering which leads to changes in mechanical properties associated to matrix carbonation (Akers, et al., 1989, Bentur, 1994 and Lhoneux, et al., 2004).

In Brazil, since 2002 Brasilit is commercializing non-asbestos product based on PVA technology and, from 2003 based on PP technology. These products have shown outstanding performance under different environment conditions either in new or in substitution to asbestos products.

AIR CURED PP FLAT PANELS

The Brasilit flat panels with PP fibers are produced in accordance to ISO 8336:1993 requirements and are classified as A3 / B3 category.

Table 8 – Properties of Flat Panels

Characteristics	*Typical Values*
Dry Density	1.45 g/cc^3
Water Absorption	max. 30%
Hydro Movement (saturated to oven dry at 100ºC)	2.5 $\pm$ 0.2 mm/m
Thermal Conductivity	0.35 W/mK
Fire Resistance	Incombustible
Equilibrium Flexural Strength	
Equilibrium Transversal Strength	17 MPa
Equilibrium Longitudinal Strength	8 MPa
Equilibrium Average Strength (B3 ISO Class)	12 MPa
Elasticity Modulus – Average (equilibrium)	7 GPa
Saturated Flexural Strength	
Saturated Transversal Strength	11 MPa
Saturated Longitudinal Strength	5 MPa
Saturated Average Strength (A3 ISO Class)	8 MPa
Elasticity Modulus – Average (saturated)	6 GPa

Table 9 – Non-asbestos flat sheet product presentation

Dimensions			*Board Weight (kg)*	*Weight per m2 (kg)*	*Recommended applications*
Thickness (mm)	*Width (m)*	*Length (m)*			
6	2.00	1.20	24.4	10.2	Light division walls, sidings, air conditioning ducts, weatherboards, etc.
	2.40		29.4		
	3.00		36.7		
8	2.00	1.20	32.6	13.6	Internal and external wall in dry and wet areas, ordinary wall or basement cladding, etc.
	2.40		39.2		
	3.00		49.0		
10	2.00	1.20	40.8	17.0	Dry and wet areas, indoor and outdoor. Perfect for external finishing in steel or wood framing systems, thermo-acoustic insulation.
	2.40		49.0		
	3.00		61.2		

Figure 17 shows an example of non-asbestos flat sheet and corrugated roofs application in a building system.

Figure 17 – Example of application of non-asbestos fiber-cement flat sheets and corrugated roofs.

In table 10 is presented the estimative figures for both flat sheets and corrugated sheets produced and commercialized in Brazil by Brasilit.

Table 10 – Estimate area for Brasilit non-asbestos production for the period between 2001 to 2005.

Type of reinforcement fiber	*Production in Kton*	*Production in million of m2*
PVA – period of 2001 to 2003	643	75
PP – period of 2003 to 2005	1,012	119
TOTAL	1,655	194

Note: Estimate from 2001 to 2005 considering density = 1.45 g/cc; Waving coefficient = 1.18, weight/m2 = 8.55 kg.

OTHER APPLICATIONS

The new product FibraSHIELD®Mono – a high tenacity PP fiber can also be used in application for cement reinforcement matrix to reduce plastic shrinkage on concretes according to ICC-ES AC 32:2003 testing procedure. The figure 18 presents the cracking reduction according to its dosage in the concrete.

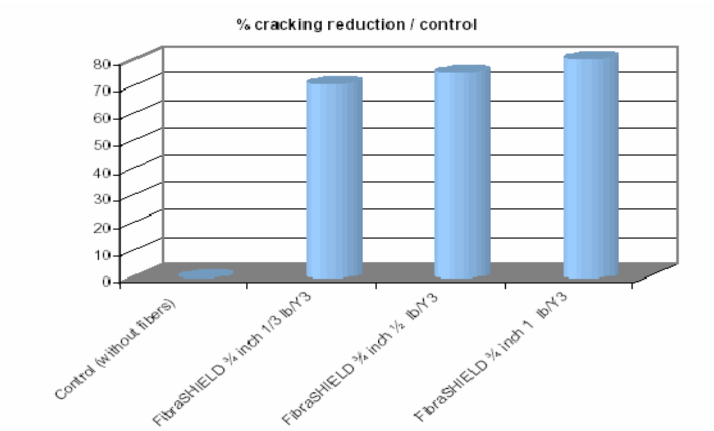

Figure 18 – Percentage of cracking reduction using FibraShield®Mono anticrack High tenacity PP fiber.

CONCLUSION

Since 2002 all the production lines of Saint-Gobain Brasilit have been converted to non-asbestos products and have already produced about 1,6 million ton, representing around 200 millions of square meter of roofing material.

The use of PP Brasifil - the high tenacity polypropylene fiber technology for fiber-cement products is a real alternative for Brasilit as its technology is already developed and adopted in all production lines. As recognition of that, a recent technology transfer agreement has been signed between Brasilit and Everest Industries, a fiber-cement producer in India.

In Brazil, although government has not achieved a consensus on the ban issue of asbestos, the market for non-asbestos products has shown gradual evolution every year.

Continuous improvements are on the way to increase the number of applications such as anti-crack and composite reinforcement. With the replacement of asbestos, flat sheets for panel cladding are a real opportunity for the building market boosted by the steel frame building system.

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