DEVELOPMENT OF NON-ASBESTOS FIBRE CEMENT PRODUCTS IN CHINA

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ABSTRACT

Over a long period of time asbestos cement (AC) was the sole fibre cement product in China. Within the last twenty years three series of non-asbestos fibre cement products have been developed. They are (a) autoclaved cellulose fibre-reinforced cement (CCA), (b) vinylon fibre-reinforced cement (VRC) and (c) glass fibre-reinforced cement (GRC). In this paper the raw materials, manufacturing processes, key technological measures in production, physical and mechanical properties, durability, as well as applications for these non-asbestos products are presented. Nowadays, AC products and non-asbestos cement products are still co-existing in the country; and even though the annual output of the former is higher than that of the latter, non-asbestos cement products represent, after all, the future development of the fibre cement industry in the country.

KEYWORDS:

Non-asbestos; Fibre cement; Cellulose fibre; PVA fibre; Glass fibre

INTRODUCTION

China was for a long period of time, and still is, one of the bigger countries in the production and application of asbestos cement (AC) products in the world. Since the middle of the 1970s, especially, many AC corrugated sheet factories, most of which belong to rural enterprises, have been popping up like mushrooms. So far there are still more than 400 AC corrugated sheet factories and not less than 600 production lines. In recent years the annual output of AC corrugated sheets even reached as high as 300 million m^2, which corresponds to 79 % of the total output of fibre cement roof and wall materials in the country, as shown in Figure1 (excluding GRC products).

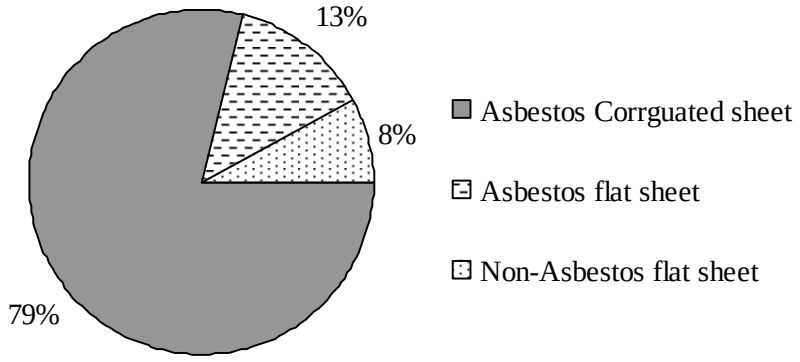


Figure 1—The share of AC corrugated sheet in total output of fibre cement roof & wall materials in 2005

Dating from the beginning of the 1980s, a great change has taken place in the international AC industry. In consideration of the health hazard of asbestos dust, more and more countries banned the use of asbestos; as a result much AC production converted to non-asbestos production. Under these circumstances a heated controversy is still on-going in China, regarding using asbestos or abandoning it. Both controversial groups advocate as follows: the one group, including the leaders of asbestos mines and many of the AC producers, holds the views of still using asbestos to produce asbestos-containing products; and the other group, represented by some researchers of the China Building Materials Academy (CBMA) and certain enterprising persons, stands for promoting the development of non-asbestos products. Due to the intensive research and development works of CBMA researchers cooperating with some factories in the last twenty years, three series of non-asbestos fibre-reinforced cement products have been successfully developed. These are autoclaved cellulose fibre-reinforced cement (CCA), vinylon fibre-reinforced cement (VRC) and glass fibre-reinforced cement (GRC). Nowadays the production and use of chrysotile asbestos-containing products have not yet been banned in China; AC corrugated sheets especially are still being produced and used in large quantities. Nevertheless, non-asbestos products represent the future development of the fibre cement industry in the country.

AUTOCLAVED CELLULOSE FIBRE-REINFORCED CEMENT (CCA)

The abbreviation CCA is different from that for air-cured cellulose fibre-reinforced cement (ACC). In fact the latter does not exist in China. CCA in China is always called as autoclaved cellulose fibre-reinforced calcium silicate or non-asbestos calcium silicate.

CCA products are mainly made from cellulose fibre as a substitute for asbestos, OPC and siliceous material as binder, certain additives and water. In general, unbleached Kraft or bleached pulp and occasionally a limited quantity of waste paper are used as cellulose fibre. Ground silica sand, fly ash or both being simultaneously added are used as siliceous material. After formation of the semi-products, autoclaving plays the important role of achieving strength and other properties of ACC within a short period of time. During autoclaving at the temperature in the range of 170°C~190°C, calcium hydroxide derived from OPC can react vigorously with silica from the siliceous material to form tobermorite crystals and other hydration products. Though under the autoclaving cellulose fibres will suffer the attack of calcium hydroxide and then be damaged to a certain extent, their reinforcing effect can still be maintained in CCA for a long period of time.

In comparison with the ACC product, CCA products have the following benefits:

(a) The production period can be reduced from 21~28 days to only 2~3 days, and thus the turnover rate of circulating funds for the manufacturers can be speeded up

(b) The linear variation of the products with the change of moisture can be reduced

(c) The efflorescence on the surface of the products can be avoided

(d) The fireproof capacity of the products can be increased, because they don't explode in the fire

According to the fabrication process of CCA boards, there are now two categories being produced and used in China, i.e. conventional CCA board produced by traditional wet process, and CCA boards produced by extrusion process (extruded CCA board).

Conventional CCA board

Since the beginning of the 1990s a great number of autoclaved AC flat board production lines have been set up successfully, among which are several flow-on lines and most are Hatschek lines. So far there are more than 30 factories and at least 50 production lines for producing these boards. In the last eight years some factories have changed their products from AC to CCA. The total output of CCA flat boards reached 30 million m^2 in the last year, which corresponds to 38% of the total output of fibre

cement flat boards. Accordingly, though the share of CCA is less than that of autoclaved AC flat board, it however seems that the annual output of the former will be steadily increased in the coming years due to the great demands of home and foreign markets.

The large-sized CCA flat boards (length—2400~3000 mm, width—1200 mm, thickness—4~12 mm) are mainly used for interior walls and partitions. Some factories also supply pre-fabricated sandwich panels composed of two CCA board facings and a lightweight core of cement mortar with EPS particulates.

In general, CCA boards can be classified into three grades according to their density, as follows: low density (LD)—in the range of 0.8~1.0 g/cm^3, medium density (MD)—in the range of 1.2~1.4 g/cm^3 and high density (HD) — in the range of 1.5~1.7 g/cm^3. For making HD grade CCA board it is necessary that the production line be equipped with a stacking-type hydraulic press to put additional pressure on the green boards. Recently, large-sized HD grade CCA boards with a brand name 'Kafu' are being produced by the Jiangsu Ai Fu Xi New Building Material Co., Ltd. The 'Kafu' CCA boards are made with a specially designed recipe, on a 3 vats Hatschek machine attached with a 9,000 t hydraulic press. The property test results of the boards are listed in Table 1. The surfaces of these boards have been sanded and painted with coloured coating, and supplied with a set of necessary accessories. These boards can be used not only as high quality interior walls for buildings and substructures (as an example, the boards are used in the South Station of Shanghai Subway Line No.1; see Figure 2), but also as exterior walls of buildings (as an example, the boards are used on exterior walls of Sino-French Centre on the campus of Shanghai Tongji University; see Figure 3) .

Table 1— Property test results of 'Kafu' CCA board

Property	Test value
Density (g/cm^3)	1.5~1.7
Bending strength* (MPa)	18~20
Impact strength* (KJ/m^2)	1.8~2.0
Screw pull-out force (N/mm^2)	80~90
Water absorption (%)	25~28
Wet expansion rate (%)	0.12~0.15
Thermal conductivity (W/m·K)	0.40~0.45
Brinell hardness	86~90
Frost-thaw resistance (25 cycles)	Passed
Impermeability (24h)	Passed
Combustibility	Incombustible, grade A

*Average value of the strength parallel & perpendicular to fibre

The small sized CCA boards (length—600~1200 mm, width—600~1200 mm, thickness—4~8 mm) are mainly used as ceilings for buildings. There are several types of these boards; such as perforated for sound absorption, relief sculpture, pressed pattern, etc.

Under normal conditions it is not necessary to add silica fume to produce CCA boards on Hatschek machine; as an exception, the Zhejiang Hailong New Building Material Co., Ltd has been using this additive for several years, mainly for overcoming the delamination of the green CCA boards. It seems that this measure may also be conducive to improving the freeze-thaw resistance of the boards.

Figure 2—'Kafu' boards used as interior walls in the South Station of Shanghai Subway line

Figure 3— 'Kafu' boards used as exterior walls on the Sino-French Centre of Shanghai Tongji

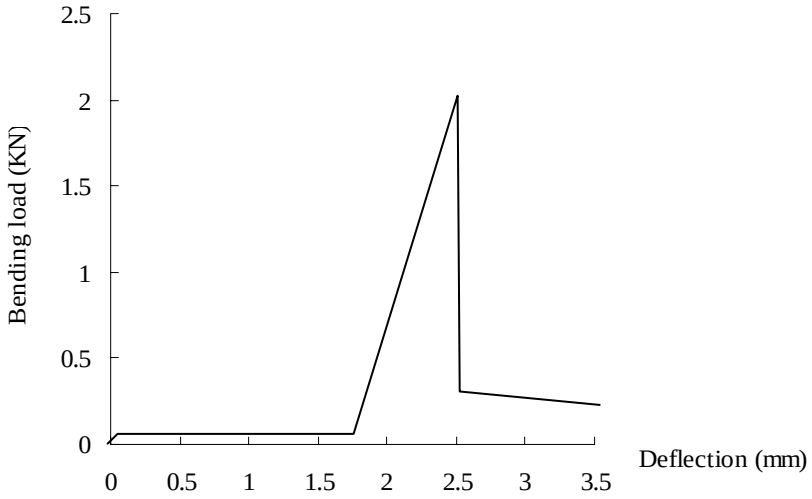
Many Chinese architects have already recognized CCA boards, which have been used in quantity in some state key construction projects, such as the National Grand Theater and the National Stadium—the Grand Stadium of the 2008 Beijing Olympic Games.

Extruded CCA board/panel

In recent years, two typical extrusion production lines for CCA wall products have been set up on the basis of importing the advanced overseas technology and equipment. One production line situated in Suzhou Industrial Estate and owned by the Beijing New Building Material Public Co., Ltd., is for the production of CCA siding boards, with an annual production capacity of 1.8 million m^2 (based on the thickness of 15 mm). The other one, situated in Tianjin and owned by Tianjin Construction Engineering New Wall Materials Co., Ltd., is for the production of CCA hollow panels with an annual production capacity of 1 million m^2 (based on the thickness of 50 mm).

In comparison with the traditional wet process, the vacuum-high pressure extrusion process is characterised by the cleanliness of the whole production process (no waste water and residues discharged), integrated structure of the products and the diversification of the products (products with different profiles produced in the same production line). The only shortcoming of the extrusion process is that the width of the products is generally limited to not greater than 600 mm.

The siding boards produced in Suzhou are made with cellulose fibre, polypropylene fibre (PP fibre), OPC, fly ash, ground silica sand, plasticising agent (cellulose ether), water, etc. Cellulose fibre is obtained by dry-disintegrating cardboard to a certain fiberisation degree. Because the maximum autoclaving temperature of the semi-products is not higher than 170℃, PP fibre can still provide its residual strain capacity in the hardened product; that is shown in Figure 4 (the relationship between



Sample size: length 300 mm, width 250 mm, thickness 15 mm
Span: 250 mm, loading rate: 1~3 mm/min.

Figure 4— Relationship between bending load and deflection of the extruded CCA sample

bending load and deflection of the extruded CCA sample).

According to the feature of the cross section of the CCA siding boards, they are classified in two series: S series board with solid cross section, and K series board with cavities on cross section. There are different surface patterns and colours for the S series board and the size of this series board is as follows:

Figure 5— Some types of K series

length—3000 mm, valid width—455 mm, thickness—15 mm. According to the surface pattern, thickness and the dimension of groove and tongue, the K series board can be further classified as several types. Figure 5 shows some types of this series. The size of the K series board is as follows: length—2400~3000 mm, valid width—300 mm, thickness—15~27 mm. The property test results of K series boards are listed in Table 2.

Table 2— Property test results of K series siding board

Property	Test value
Density (g/cm^3)	1.7~1.8
Bending strength (MPa)	15~18
Impact fracture work (kg·m)	1.2~1.5
Water absorption (%)	16~18
Wet expansion rate (%)	0.14~0.20
Thermal conductivity (W/m·K)	0.18~0.20
Sound insulation (dB)	31~32
Frost-thaw resistance (300 cycles)	Passed
Impermeability	Passed
Combustibility	Incombustible, grade A

The hollow panels produced in Tianjin are made with cellulose fibre, OPC, fly ash, ground silica sand, plasticizing agent (methyl cellulose), water etc. Cellulose fibre is obtained by dry-disintegrating waste magazine paper to a certain fiberisation degree. The panels are characterised as high density wall (1.8~2.0 g/cm^3), smooth surface, lightweight (the cavity percentage of the cross section is greater than 50 % by volume), dimensional stability and easy for installing cables and pipelines. These products are mainly used for interior walls, partitions and exterior walls of buildings. Figure 6 shows a hollow panel after extruding and cutting on the conveyor.

Figure 6—A hollow panel on the conveyor after extruding and cutting

VINYLON FIBRE-REINFORCED CEMENT (VRC)

'Vinylon' is a commodity name of polyvinylalcohol (PVA) fibre. PVA fibre used as reinforcement for cement matrix is different from conventional PVA fibre due to its higher mechanical property (see Table 3). For making a distinction between the two kinds of PVA types, the fibre used in fibre cement is named as high modulus PVA fibre (HM-PVA), or high modulus vinylon (HM- vinylon).

Table 3— Comparison mechanical properties between two kinds of PVA fibres

Fibre kind	Density (g/cm^3)	Tensile strength (MPA)	Young's modulus (GPA)	Ultimate elongation (%)
HM-PVA	1.3	1400~1600	34~36	6~7
Conventional PVA	1.3	600~700	5~7	16~17

In the middle of the 1980s, HM-PVA fibre was trial-produced successfully in China and then put into quantity production. On the above basis, CBMA cooperated with some AC product companies to trial-produce non-asbestos VRC corrugated and flat sheets successfully on the existing Hatschek production lines, by taking several effective technical measures. However, the production of VRC corrugated sheets was difficult to be popularised and that of VRC flat sheets was only adopted in individual companies, largely due to the higher cost of the finished products compared with AC products.

There are now five vinylon companies in China producing HM-PVA fibre, with a total annual production capacity of 100,000 t.

In the late 1990s, referring to the experience of producing VRC sheets, the Qingdao Yuanding Non-metallic Product Co., Ltd., produced VRC cable protection pipes on the existing AC pipe-making machine, and then now these products are also being produced by other companies and used widely in the country, due to the demands of the market. In the reconstruction projects of electric cable networks in many cities of China, the original cables, which are suspended in the air, shall be transferred embedding underground, so a large quantity of non-metallic cable protection pipes is needed.

Thus far there are 10 factories and 25 production lines producing fibre cement cable protection cables. In the last year the total output of these pipes reached at least 8,000 Km (based on the pipe with an inner diameter of 150 mm); however the share of VRC pipes was still less than that of AC pipes.

Figure 7-VRC cable protection pipes with fittings

The specification of VRC cable protection pipe is the same as AC cable protection pipe which follows: length—3000mm, 4000mm; inner diameter—100mm, 125mm, 150mm, 175mm, 200mm. The surface of both ends of each pipe is turned in the definite length (65mm). All pipes are supplied with the necessary joint fittings (see Figure 7). As shown in Table 4, the pipes are classified in three grades (A, B and C), according to their working functions. The mechanical performance for each grade shall satisfy the requirements, and the impermeability for all grades is the same. The working function for each grade is as follows: (a) grade A, concrete encased or embedded under sidewalk; (b) grade B, embedded under traffic lane for 20t trucks; (c) grade C, embedded under traffic lane for > 20t trucks.

Table 4— Requirements of mechanical property and impermeability for VRC cable protection pipe

Pipe grade	Inner diameter (mm)	Bending load (kN) >	Compressive load (kN/m) >	Impermeability
A	100	5.0	17.0	While the pipe being full of water with pressure of 0.1 MPa for 60s, not any wet trace appearing on outside surface of the pipe
	125	9.0		
	150	12.0		
	175	17.0		
	200	22.0		
B	100	6.0	27.0	
	125	11.0		
	150	16.0		
	175	20.0		
	200	26.0		
C	150	21.0	48.0	
	175	25.0		
	200	30.0		

VRC cable protection pipes are made with HM-PVA fibre, sepiolite fibre, OPC, water, etc., among which sepiolite fibre is used as process fibre for reducing the loss of cement particles during slurry filtration. In consideration of that it is difficult to distinguish sepiolite fibre from asbestos, and even sometimes sepiolite fibre may be contaminated with asbestos, some VRC manufacturers have decided trying to substitute cellulose fibre for sepiolite fibre and at the same time to add microsilica for improving the bond between PVA fibre and cement matrix. The Zhejiang Gaoxin Non-metallic Product Co., Ltd. has been producing VRC pipes successfully according to the above advice, and their products have already been exported to Germany, where these pipes are to be used as sewer pipes and shafts of columns.

GLASS FIBRE-REINFORCED CEMENT (GRC)

The long-term durability is a key problem in the development of GRC. Though the alkali-resistance of AR-glass fibre is much better than that of ordinary glass fibre, the durability of GRC made with AR-glass fibre and ordinary Portland cement (OPC) is still poor, especially when exposed to a wet environment or natural weather. Based on a series of tests and the valuable native and foreign experiences, the researchers of CBMA have been taking the so-called “double assurance” technical way for considerably improving the long-term durability of GRC. “Double assurance” means that a durable GRC shall be made with AR-glass fibre and low-alkalinity cement. In the middle of the 1970s, a new kind of low-alkalinity cement, i.e. sulphoaluminate cement (SAC), was developed by CBMA.

There are two kinds of SAC used in GRC production, i.e. rapid hardening SAC (R-SAC) and low alkalinity SAC (L-SAC). The pH value of cement slurry for R-SAC is not greater than 11.7 and that for L-SAC is not greater than 10.5. In general, the former is mainly for producing GRC products installed indoors and the latter is for those used outdoors. Due to the difference of hydration products between SAC and OPC, in addition to the lower pH value of the cement slurry, the former is also characterised as fast setting, high early-strength, non-shrinkage and good impermeability. The annual output of SAC reaches about 1 million tons manufactured by over 10 cement plants.

In recent years high zirconia-containing AR-glass fibres (ZrO_2 content not less than 16 % by weight) are being produced and used as rovings or chopped strands for most GRC products. For some GRC

products, scrims made with A- or E-glass fibres and protected with alkali-resistant coatings, are also used.

The main GRC fabrication processes, i.e. direct spray, spray-suction, pre-mix and scrim lay-up, are still widely used. Among them, most large-sized GRC products have been manufactured by direct spray process during the past years. However, there are some limits in use for this process, especially for making complex shape GRC products with small openings and/or with sloping surfaces. About 3 years ago, a newly-developed process, i.e. pre-mix spray process, was adopted. Comparing with the direct-spray process, the new process has a lot of advantages, such as flexible output rate, reduced manpower, no overspray, guaranteed fibre content, cleanly producing, fine surface detail and good uniformity of the products, etc. The pre-mix spray process is very suitable for making architectural GRC decorative components, landscape and environmental art works. In recent years more than ten pre-mix spray process lines have been set up. Normally the mechanical strengths of GRC produced by the pre-mix spray process are higher than those produced by the pre-mix process (see Table 5), due to uniform distribution and 2D random orientation of the fibre strands.

Table 5— Mechanical strengths of GRC made by different processes

Process	MOR (MPa)	Impact strength (KJ/m^2)
Pre-mix spray	14-16	8-10
Pre-mix	10-12	6-8

The Changchun Century Movie Park, also named as the Oriental Hollywood, was finished in 2004 and there are about 70,000 m^2 GRC architectural image decorative components and landscape decorative artworks cast in-site by the Nanjing Libeida Industry Co. Ltd., by using the pre-mix spray process. Figure 8 shows one of the scenic spots constructed with GRC components and artworks in the movie park.

Figure 8— A scenic spot constructed with GRC in Changchun Century Movie

Besides GRC hollow core lightweight partition panels and GRC roof slabs with pre-stressed concrete ribs for grid structures, GRC tube-shaped formworks are, in recent years, being produced and used widely. These formworks are used as permanent shuttering in the construction of cast-in-place reinforced concrete cavity flooring, so that the total weight of the floor can be reduced and the beams under the floor are not needed. The GRC tube-shaped formworks are mainly produced by scrim lay-up process. Their section is normally circular, but is also occasionally oval or rectangular. The dimensions of the products with circular section are varied in following ranges: length—400~2000 mm, outside diameter—100~300 mm, wall thickness—5~7 mm. Figure 9 shows a cast–in-place reinforced concrete cavity floor constructed with GRC tube-shaped formworks.

Figure 9— GRC tube-shaped formworks used in cast-in –place reinforced concrete cavity floor

It is estimated that in recent years the annual cast quantities of reinforced concrete cavity flooring constructed with GRC tube-shaped formworks are not less than 10 million m^2 and a great demand for these formworks will be further sustained for several years to come.

It can be expected that with the fast growth of China's economy, the application fields of GRC may be further widened.

CONCLUSION

Due to the sustained and unremitting efforts made by many foresighted and sagacious Chinese scientists and experts, the old aspect of China's fibre cement industry has been changed greatly; which means that the long period of the solely existing fibre cement product, AC, is closed, and a new transition period of AC and non-asbestos fibre cement, co-existing, has appeared. The main non-asbestos fibre cement products being developed are CCA, VRC and GRC. Though at present the share of these non-asbestos products in the annual fibre cement total output is still less than that of AC, the manufacturing processes and application techniques of the former are getting more and more ripe. Furthermore, many people in the country have already understood that certain properties of non-asbestos fibre cement are even better than those of AC. Undoubtedly, non-asbestos represents the future development of the fibre cement industry in China.

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