BI-COMPONENT AND MONO-COMPONENT POLYPROPYLENE FIBRES USED IN FIBRE CEMENT FOR REINFORCEMENT

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ABSTRACT

The fibre cement industry in Europe and Australia has 30 years of success with asbestos replacement materials. The first generation of air cured products developed in Switzerland used a combination of polyvinyl alcohol (PVA) fibre from Kurraray Japan, combined with refined cellulose fibres. James Hardie used cellulose fibres in an autoclaved technology. Since the use of PVA fibres in the industry, more interest has evolved in the use of polypropylene (PP) fibres as a possible alternative to PVA. This paper describes the use of PP fibres (bi-component and mono-component) developed by Oerlikon Neumag for use in the fibre cement industry. The fibres have been assessed on a pilot industrial Hatschek machine for their suitability in fibre cement products and also accelerated ageing test has been used to predict the service life of the product. The newly developed PP fibres from Neumag have proved to be viable alternative fibres for PVA in the fibre cement industry.

KEYWORDS:

Fibre cement; synthetic fibres; bi-component; polypropylene; Hatschek.

INTRODUCTION

It has now been 35 years since the first serious asbestos replacement program were initiated in the fibre cement industry (Akers et al., 1989a). Eternit Switzerland and James Hardie Australia both started simultaneously and research programs were the first priority for both parties concerned. In fact it was realized that this strategy was directly related to the survival of the fibre cement industry in both countries. For varied reasons the Australians eventually developed the autoclaved technology and the Swiss pursued the air cured technology. Today the autoclaved technology has proved to be very successful for internal applications and sidings whereas the Swiss air cured technology can be used both. It would appear after 35 years however that the air cured technology is the preferred technology for roofing and facade application and autoclaved for internal applications. These strategies are governed by costs and raw material availability amongst others. The air cured technology uses a combination of synthetic fibres and refined cellulose pulps where the autoclaved technology only uses cellulose fibres for reinforcement. The mix formulation for autoclaved technology has not changed much over the last 35 years. This is certainly not the case for the air cured technology. Varied additives have been used in the air cured technology to accommodate for the cost and needs for the replacement program in each country where replacement of asbestos fibres in fibre cement products has been implemented. One of the major cost factors in the mix formulation is the synthetic fibres used. These fibres satisfy the long term durability requirements in air cured products (Akers et al., 1989b, De Lhoneux et al., 2002) Therefore since the beginning of the development of the air cured technology with PVA fibres there has been a consistent drive to look for alternative fibres to PVA. One of the most obvious choices was PP (De Lhoneux et al., 2008), however in the early 80's the elastic modulus and bonding to fibre cement of PP fibre was very inferior to PVA and therefore never considered or found to be a very good substitute. Recently, much research has been performed in this direction and there are many types of PP fibres available today, which can be considered to be acceptable replacements for PVA. Neumag have worked together with fibre cement specialists and fibre cement companies in the past few years and this paper describes the latest development at Neumag. The fibres were manufactured by Oerlikon Neumag and tested on a pilot machine with a very advanced and respected fibre cement producer in Europe.

The objective was to evaluate pressed and unpressed air cured fibre cement products with mono- and bi-component PP for their suitability for commercial products.

POLYPROPYLENE SHORT-CUT FIBRE MANUFACTURING PROCESS AT NEUMAG

Oerlikon Neumag has been producing equipment for the synthetic fibre industry for more than 60 years. The biggest chemical fibre producers rely on this equipment. Besides producing equipment Oerlikon Neumag actively develops production processes for advanced fibres such as the herein mentioned advanced reinforcement fibres (Ikai et al., 2006).

The production process for the bi-component fibres is described in the following subsections.

Spinning

The pre-oriented bi-component polypropylene fibres are produced in a common melt-spinning process. The polymer together with the functional additives are melted in an extruder and spun through several round spinnerets. Several thousand of filaments are spun from each spinneret.

Just below the spinnerets, the hot polymer melt is cooled by conditioned air. The quenching is done radially from inside to outside (Fig. 1). These early process steps are very important as they lay the basis for many of the fibres final properties. For better cohesion a finish is then applied and the fibres are wound onto bobbins. One bobbin is produced per spinning position about every 45 min. Due to the spinning speed the polymer molecules are pre-oriented in the fibres. The degree of orientation in the fibres has a big impact on the final tenacity of the fibres.

One spinning position can produce about 100 kg/h.

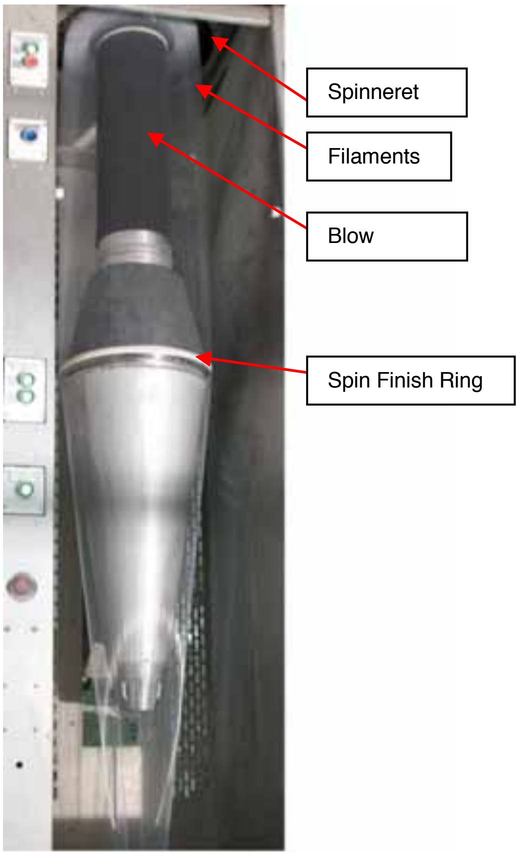

Fig. 1: Oerlikon Neumag Spinning Position

Drawing

All the produced bobbins from one day are processed on the fibreline the following day. Several hundred of bobbins are stacked on a creel stand, i.e. a bobbin holder, and as one large tow fed to a tow guiding stand. The different yarn tensions from the bobbins are equalized and the tow is guided to the first draw stand. In the fibreline there are four draw stands in total which all run at slightly different speeds; from 20 m/min on the first up to 120 m/min on the last draw stand. In between there are the so called drawing zones where the tow is heated in a hot air channel. This is required for a uniform drawing process. Each drawing zone is individually controlled to avoid fibre fusions and breakages and to achieve the highest fibre tenacity.

Cutting

The fibres then have almost all their final properties and are guided to the cutter. They are cut to appropriate lengths between 3 mm and 12 mm and packed into bales. Until adding them to the cement slurry, they can be stored or shipped easily.

The fibres used in the test samples were produced on Oerlikon Neumag's pilot spinning and drawing line in Neumünster, Germany, which is used to develop new products together with customers.

The fibres are characterized through several properties which are described in the following:

- **Titer [dtex]:** weigth of the fibre per 10’000m length, measure for fibre thickness
- **Tenacity [cN/dtex]:** How much force can be applied to the fibre before breakage, normalized with fibre thickness
- **Elongation (at break) [%]:** Relative elongation of the fibre at breakage

MANUFACTURE OF FIBRE-CEMENT PRODUCTS

The products were manufactured on a pilot Hatschek machine, using 2.2 % PP fibres and a standard portland cement. Cellulose (refined) pulp was used as a process fibre which is standard practice in the fibre-cement industry. The process fibres are used on the Hatschek machines as a natural filtration “mat” to keep the cement on the sieve. PP fibres with these dimensions used in the fibre cement industry do not perform this function. The PP fibres investigated were; mono-component (PP) with additives and bi-component (PP) with PP as the core and PP with additives in the sheath.

The fibre properties are listed in Table 1.

Table 1 – PP fibre properties

	Tenacity [cN/dtex]	Titer [dtex]	Elongation [%]	Length [mm]
Mono-component	9.50 9.50	1.10 1.10	21.0 21.0	6.6 9.9
Bi-component	9.97	1.51	19.30	6.6

Products were manufactured according to standard Pilot Hatschek procedures with a thickness of 6.5 mm; some were pressed afterwards to a thickness of 5 mm. After this the initial curing was for eight hours between steel plates and thereafter wrapped in plastic and cured at ambient conditions in a laboratory for 28 days.

Accelerated ageing test

The samples were subjected to 30 days in an accelerated ageing test, which consisted of soaking and drying and also subjected to a CO_2 environment in order to accelerate the carbonation of the matrix.

The cycle was (24 h)

9 h submerged under water at 20°C

1 h oven drying at 60°C

5 h carbon dioxide environment

8 h drying at 60°C in an oven

1 h cooling down to 20°C

Flexural tests and results

The specimen size was 250 x 250 mm with a thickness of 6.5 mm (unpressed) and 5.0 mm pressed. The span was 200 mm tested at a crosshead speed of 30 mm/min. 5 specimens were tested per fibre type and the arithmetic mean value recorded. Prior to mechanical characterization the products were stored at ambient conditions in a laboratory for five days. The Flexural Strength, E-Modulus, Fracture Energy were calculated

from the load deflection curves before and after the accelerated ageing (tested according to EN 12 467). The manufacture of fibre cement products on a Hatschek machine is such that a preferred orientation of the synthetic fibres in the production direction occurs. Therefore it is standard practice to test specimens in parallel (P) to the machine direction and perpendicular (A) to the machine direction.
The results given in Table 2 represent the tests performed accordingly.

Table 2 – Test Results Fibre Cement

P: parallel to mach. dir.	**Flexural Strength (MPa)**						**E-Modulus (GPa)**				**Fracture Energy (kJ/m^2)**			
A: perpendicular to m.d.	**Pressed**			**Unpressed**			**Pressed**		**Unpressed**		**Pressed**		**Unpressed**	
	P	**A**	**Average**	**P**	**A**	**Average**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**
Mono-Comp. 6.6 mm														
before ageing	22,2	31,9	27,1	13,6	17,7	15,7	17,2	17,7	9,8	9,2	2,1	5,5	1,3	3,0
after accel. ageing	22,3	30,6	26,5	14,6	17,9	16,3	19,9	21,3	11,6	11,4	0,7	3,3	2,2	4,6
Mono-Comp. 9.9 mm														
before ageing	22,7	31,2	27,0	13,4	18,4	15,9	16,3	16,0	9,1	8,8	2,9	6,3	4,3	5,9
after accel. ageing	23,0	30,3	26,7	15,2	19,3	17,3	19,1	19,7	11,5	10,5	1,3	4,1	2,8	7,1
Bi-Component 6.6 mm														
before ageing	25,9	29,3	27,6	-	-	-	14,3	17,4	-	-	6,0	6,5	-	-
after accel. ageing	26,6	31,0	28,8	-	-	-	19,4	24,2	-	-	3,4	3,3	-	-

Discussion on flexural test results

When comparing fibre length 6.6 mm with 9.9 mm for mono-component fibres before ageing, it appears that there is no significant advantage in using longer fibres with regard to strength contribution with high density (pressed) and lower density (unpressed) products. This is however not the case for fracture energy. The longer fibres (9.9 mm) show a significant contribution to fracture energy. This is most probably related to the increased fibre pull-out behaviour of the longer fibres. The bi-component fibres (6.6 mm) compared with mono-component fibres (6.6 mm) showed no significant advantage for pressed products. Here, the average value of parallel (P) and perpendicular (A) were used for the comparison. It appears that the bi-component fibres have a different orientation to mono-component fibres for the parallel test series because the values for bi-component are considerably higher than for mono-component fibres. This however can be related to the process variability on the Pilot Hatschek machine and therefore the interpretation of orientation in this case should be treated with a certain amount of caution. Although the strength contribution of bi-component fibre may not be very different from mono-component fibres, the contribution to fracture energy of bi-component fibres is very significant. Bi-component fibres can be considered to be superior to mono-component in pressed products with regard to toughness contribution. This is most probably related to the interfacial bond where the sheath of the bi-component fibre has formed a good bond with the cement matrix whereas the core is responsible for the strength. Comparing pressed products with unpressed products (mono-component) it is clear from the results that the reinforcing potential of the fibre is not used to its full advantage. Strength values are significantly lower for unpressed products. Looking at a typical stress/deflection curve for pressed (Fig. 2a) products and unpressed products (Fig. 2b), it is clear that the dominating failure mode is fibre pull-out, which is more advanced in unpressed products. It can be argued here that if the strength is lower and the elongation to failure is greater for unpressed products, the fracture energy should be higher for unpressed products. However the results in Table 2 do not support this hypothesis. The fracture energy is a defined value related to the area under the stress/deflection curve measured to the highest stress value where the product is considered to have failed. In the example given in Fig. 2 it is clear that the area under the stress/deflection curve for Fig 2b is less than for Fig. 2a.

Consider now the ageing properties of the same product (Fig. 2c and Fig. 2d). It is evident that accelerated ageing results in an embrittlement of the product; it becomes stiffer (E-Modulus increase). As a result of the increase in the interfacial bond due to carbonation the pull-out behaviour is reduced. This is confirmed by inspection of the stress/deflection curves when comparing Fig. 2a with Fig. 2c and similarly comparing Fig. 2b with Fig. 2d. The results in Table 2 however show that the fracture energy values have increased (from 3.0 kJ/m^2 to 4.6 kJ/m^2) for the unpressed product. This is explained again by the definition of fracture energy given by the area under the stress/deflection curve measured to the highest stress level to failure. It is clear when comparing Fig. 2b with Fig 2d that the E-Modulus has increased with an increase in the interfacial bond (stress to limit of proportionality (LOP)). The LOP is defined as the stress at witch the linear relation between stress and strain ends. In this case at LOP the fibers begin the pull-out, however, because the interfacial bond has increased, the fibres can take more load. As the fibres do not break the stress to failure increases and at the same time the extension to ultimate failure (high stress level) is extended significantly. Therefore the fracture energy measured has increased with accelerated ageing and not decreased in the case of the unpressed product. In general, however when looking at the values given in Table 2 it is well established (Pirie et al., 1990) in fibre-cement products that ageing results in embrittlement which is normally detected by a strength increase with an associated drop in fracture energy. Comparing mono-component products (pressed) with bi-component products (see Table 2) before and after ageing, it is evident that although the strength contribution of bi-component products is not any better after ageing - the toughness (fracture energy) contribution is definitely superior for bi-component products.

Figure 2: Stress / deflection curves, 9.9mm PP fibres

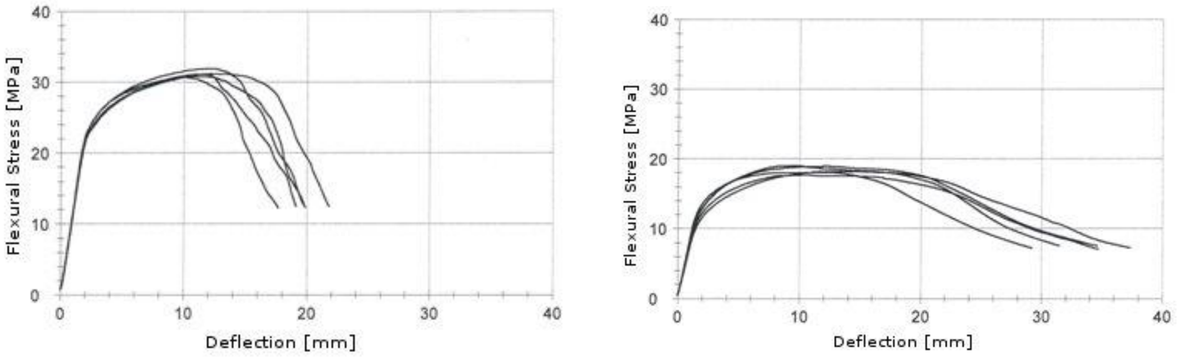

Fig. 2a: Pressed product, 28 days ageing

Fig. 2b: Unpressed product, 28 days

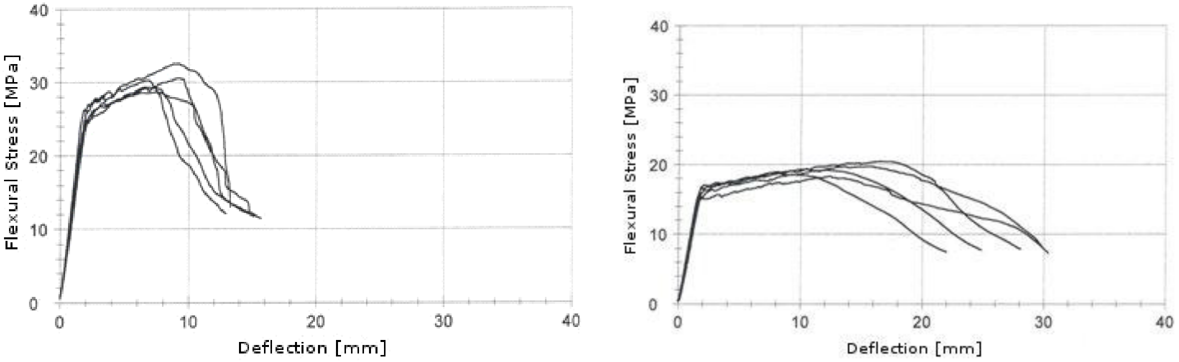

Fig. 2c: Pressed product, after accel. ageing

Fig. 2d: Unpressed product, after accel. ageing

Significance of the test results to applications in the fields

When using polypropylene fibres in fibre cement products, it is evident that the interfacial bond plays a significant role in the strength requirements of the product. For example in a facade product where strength is not as important as in a corrugated sheet for roofing, it is possible to use mono-component or bi-component polypropylene fibres for unpressed products. However for corrugated sheets, bi-component fibres would be the obvious choice. There is no real advantage in using 9.9 mm mono-component polypropylene fibres for both pressed and unpressed products. It is speculated here from the logic of the test results that bi-component polypropylene fibres in unpressed products should perform better than mono-component products.

CONCLUSIONS

Polypropylene fibres tested in this development program certainly show their suitability for fibre reinforced cement products, using Hatschek technology for air cured applications. The choice of whether to use mono-component fibres or bi-component fibres is dependent on the envisaged application of the product in the field. There is no advantage in considering 9.9 mm polypropylene fibres relative to 6.6 mm fibres.

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