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POTENTIAL USE OF POLYETHYLENE TEREPHTHALATE (PET) FIBRES IN FIBRE CEMENT COMPOSITE MATERIALS

STEPHEN A.S. AKERS, AKERS CONSULTING GMBH, MOLLIS, SWITZERLAND,
BEAUTY MTSWENI, EVERITE BUILDING PRODUCTS (PTY) LTD., GAUTENG, SOUTH AFRICA,
LOURENS OLIVIER, EVERITE BUILDING PRODUCTS (PTY) LTD., GAUTENG, SOUTH AFRICA,
JORGE FONSECA, PROPET S.A. (PTY) LTD., MILNERTON, SOUTH AFRICA
CHANDRU WADHWANI, EXTRUPET S.A. (PTY) LTD., GAUTENG, SOUTH AFRICA

ABSTRACT

PET fibres can be added to ordinary concrete to reduce plastic shrinkage cracks as well as reduce the crack widths of drying shrinkage cracks. Their effectiveness is dependent on the fibres characteristics, dosage as well as the concrete matrix. PET fibres can also be used in the fibre cement industry. The difference between concrete and fibre cement is that classical fibre cement is produced on a Hatschek machine and uses larger volumes of reinforcing fibres and the products are generally thin sheets typically between 4 and 8 mm thick. Concrete incorporates relatively small amounts of fibre, i.e. from 0.5 – 1 %. Initial tests run on a pilot Hatschek machine have indicated that PET fibres have the potential to be used successfully in fibre cement products. Durability aspects have been addressed. The main emphasis on this paper will be to present preliminary studies on the use of PET fibres in the fibre cement industry.

KEYWORDS:

Polyethylene terephthalate fibre; cement; composite; durability; accelerated ageing.

INTRODUCTION

Polyethylene terephthalate (PET) is a thermoplastic polymer resin of polyester family. PET consists of polymerized units of the monomer ethylene terephthalate, with repeating $C_{10}H_8O_4$ units. Because of its structural regularity, PET crystallizes readily above its transition temperature. The presence of a benzene ring in the main chain leads to a stiffer chain with the result that the polyester has both a higher glass transition temperature (80° C) and crystalline melting point (254° C). Polyethylene terephthalate has inherently poor chemical resistance to alkalis but good resistance to ultraviolet light.

PET is used for producing, amongst other products, plastic bottles for water, Coca-Cola, beer, etc., etc. Due to the increasing demand of searching for environmentally friendly solutions for waste materials, it was obvious that many people started looking at the possibility of recycling PET bottles. Recycling of PET bottles and reusing the base material for making new injection moulded products is not trivial especially when it involves the making of bottles for consumption of liquids mentioned above. The reason is that for hygienic purposes the PET recycled material needs to have a very high purity. Considering this aspect the cost factor then becomes an important issue as well and plays an important role in the strategic planning whether to recycle or not for drinking bottles. This resulted in the idea of using recycled PET for other products where the purity aspect was not of prime importance and led to ideas where recycled PET could be extruded for building materials such as decks or walkways for coastal resorts, etc. It was obvious then that the consideration for PET fibres for potential use in building materials such as concrete and fibre cement was a candidate for consideration. Polypropylene fibre used in the concrete industry is well known (Briggs, 2002) and much research has been performed in this field and successfully used today. PVA fibre is also known to be used in the concrete industry (Martinola et al, 2002) but it is of more particular interest in the fibre cement industry and has been used successfully in the fibre cement industry for more than 30 years. Recently however there is a lot of interest in the use of PP fibres for fibre cement products.

The use of PET fibres in the concrete industry has been researched at Stellenbosch University in South Africa through reports ISI 200-01 – Phase 1 and ISI 2007 -02 – Phase 2. These papers consider the use of PET fibres as secondary concrete reinforcement. Further, the use of PET fibres in the concrete industry has also been certified by Agrément South Africa (Certificate No. 2009/365) for the purposes of reducing the probability of plastic shrinkage "cracking".

As mentioned before the resistance to alkalis is an important consideration for the use of PET fibres in fibre cement products. This is due to the fact that the production water used on the Hatschek process in the fibre cement industry is highly alkaline (PH 12-13) and also during the curing of the product, the interfacial region (i.e. at the bond between the fibre and the cement) is highly alkaline. The question is however, what is the expected alkaline attack on the PET fibre surface during manufacture and curing. Once the product is exposed to the environment, the interfacial region becomes less alkaline due to carbonation and therefore the issue of alkaline attack on the PET fibre surface is reduced. A similar analogy is also used for PVA fibres as it is also known that standard PVA fibres exposed to highly alkaline cement slurry will also deteriorate with extended exposure. It has been proved however, (Akers et al, 1989, De Lhoneux et al, 2002) that PVA fibres, even if they are not 100 % alkaline resistant, have been used successfully over the last 30 years in fibre cement provides worldwide.

The purpose of this paper is to present results obtained from a feasibility study conducted at Everite Building Products (Pty) Ltd., Kliprivier, South Africa aimed at investigating the potential use of PET in fibre cement products using pilot scale investigations and to test their resistance to the alkaline environment of fibre cement products.

EXPERIMENTAL PROCEEDURE

Two methods of production were used i.e.:

Filter press samples made to provide input to dispersion properties of PET fibres in fibre cement slurry and at the same time provide input to a pilot scale Hatschek trial and Pilot scale Hatschek trial to assess process parameters and flexural properties before and after ageing.

Stage 1 Filter Press

Samples were manufactured using a simple filter press method. This comprised of mixing refined cellulose fibres with synthetic fibres in a high shear mixer and then adding the powders. The consistency was 20 %. The mix was poured into a filter mould and the excess water was filtered off using a vacuum pump.

The mini slabs were then placed on form plates and wrapped with plastic for three days. After three days the form plates were removed and the samples wrapped in plastic for the full curing duration. Samples were tested at 7, 14 and 28 days for physical properties.

Three mixes were used for the filter press tests, see table 1 below.

Table 1 – Mixes used for filter press specimens

	Mix 1 %	Mix 2 %	Mix 3 %
Cellulose (refined)	4	4	4
PVA	1.5	0.75	-
PET	-	0.75	1.5
$CaC0_3$	10	10	10
Micro Silica	4	4	4
Cement	80.5	80.5	80.5

A standard flexural test was used to determine the modulus of rupture (MOR)

Stage 2 Pilot scale Hatschek trials

For the purpose of this trial, similar mixes were used to those used for stage 1 and these were run on a pilot Hatschek machine using mixing procedures and process conditions and parameters used on a large production machine.

The pilot Hatschek machine was used to assess the suitability of the fibre type using Hatschek technology. The pilot Hatschek machine is in principle a simplified version of the full scale production machine and can be realistically used to test processability of fibre. Flat sheets (6 mm thick) were manufactured and cut to sample sizes of 250 mm x 250 mm. The mix variations were designed to estimate the reinforcing and durability of the products. In particular the alkaline stability of the PET fibres was assessed using accelerated ageing tests.

Table 2 – Mix Formulations

Fibre Type	Mix 1 %	Mix 2 %	Mix 3 %
PET Fibre	2	1	-
PVA Fibre	-	1	2
Cellulose	3.5	3.5	3.5
$CaC0_3$	20	20	20
Cement	74.5	74.5	74.5

Accelerated Ageing Test

The test is designed to simulate the realistic exposure of fibre cement to natural weathering. It consists of a 24 hour cycle of wetting / drying and exposure to a $C0_2$ environment. Essentially the product exposed to this test will increase in flexural strength as the cement matrix hardens. If the flexural strength drops using this test, the product durability is then suspect. One month of exposure to this test is regarded as ten years exposure to natural weathering. Flexural tests before and after accelerated ageing tests were conducted.

Cycle

- 9 hour soak under water (20° C)
- 1 hour dry in ventilated oven (60° C)
- Switch off oven
- 5 hour $C0_2$
- 8 hour dry in ventilated oven (60° C)
- 1 hour cool down to (20° C)
- 24 hour total = 1 cycle

Reinforcing Fibres

The fibres used in this study are listed in table 3 and compared with PVA fibres.

Table 3 – Fibre properties of PET and PVA used for this study

		PET	PVA
Tenacity	cN/dtex	4.5	13
Elongation	%	40	7

Titer	dtex	3.3	2.0

MANUFACTURE OF PET FIBRES (see Figures 1, 2, 3)

PET fibres are produced from recycled waste material using standard fibre extrusion technology. Once collected bottles and other PET packaging are cleaned and flaked, they are re-melted and turned in to solid PET pellets. These pellets are subsequently held in silos in order to allow pre-extrusion mixing of various polymers (pellets) viscosities, colours, qualities and shapes, ultimately ascertaining homogeneous raw material with certain required properties necessary for extrusion.

"Regain" moisture is then almost completely removed from the polymer/pellets during drying stage and they are extruded (molten) as well as air-dried (cooled) as solid or hollow endless filaments of predetermined thicknesses (Decitex/Denier).

Thousands of filaments are then moved to the drawing process where they are fed in parallel to a series of heated rolls (Septets) where they are stretched 3-4 times their original size to pre-determined tensile and other properties which are imparted by drawing filaments more or less during their glass transition state.

Once these properties have been achieved, the filaments are either, crimped into a zigzag or spiral shape for use in textiles or left un-crimped in a straight shape for use in concrete and cementitious applications. After the mentioned properties have been subsequently set (cured) with further heating, the filaments are cut in to pre-established lengths as required by customers and packaged in bales of approximately 350 kg to allow easier and affordable transporting to the various customers.

Figure 1:

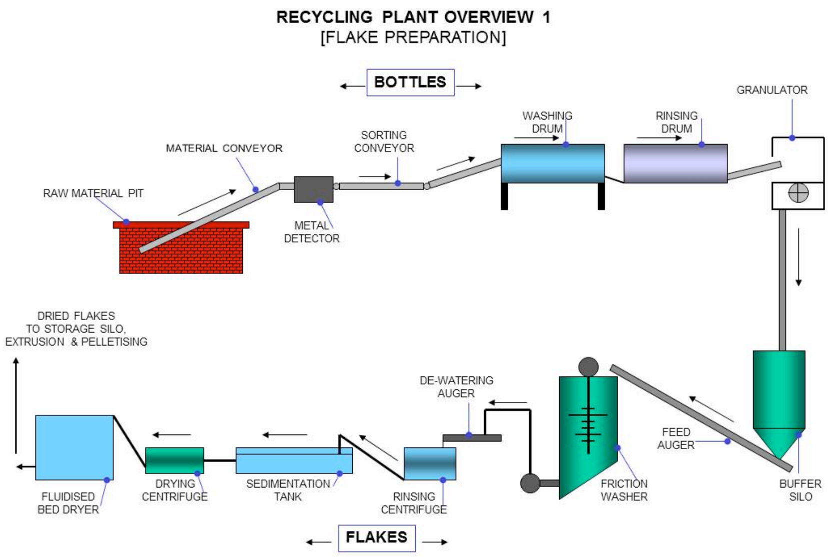


Figure 2:

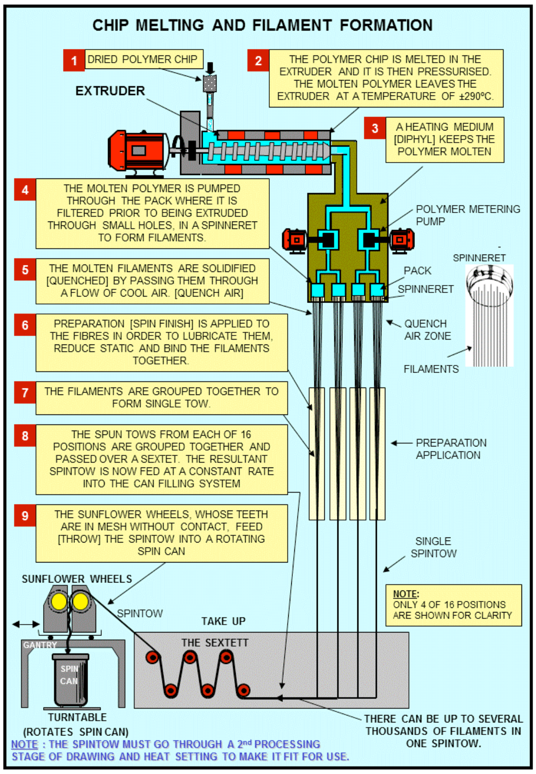
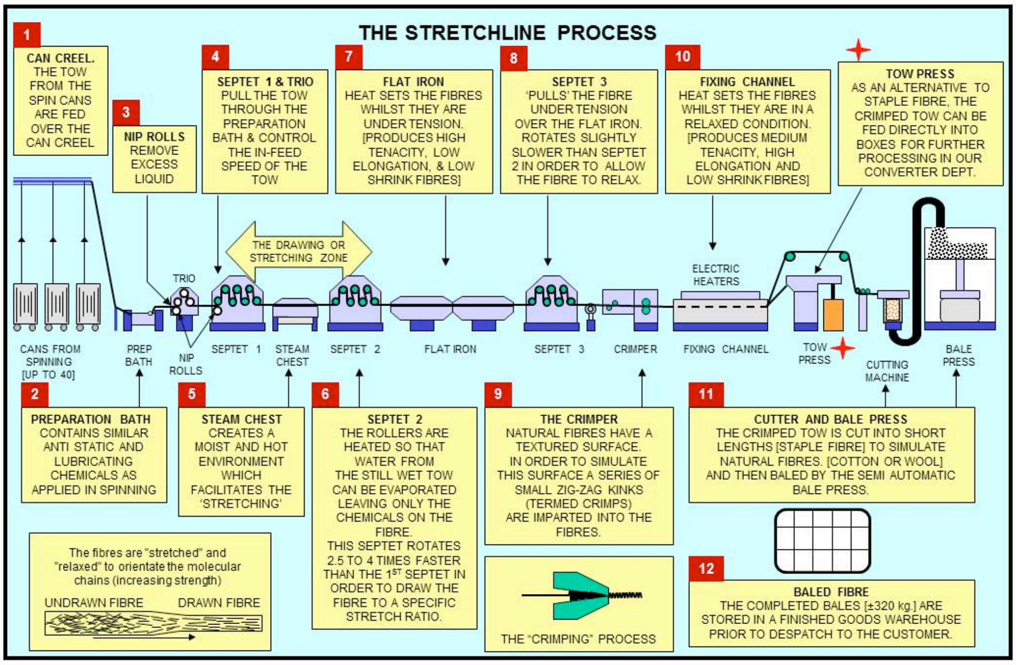


Figure 3:

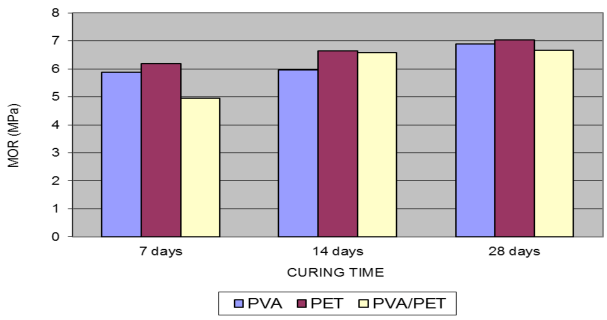


RESULTS AND DISCUSSIONS

Filter press trials (stage 1)

The flexural strengths measured after 7, 14 and 28 days are given in Fig. 4 below

Fig. 4 Modulus of rupture with time



Test results shown in Fig. 4 were found to be rather surprising. In particular the fact that the tenacity for the PET fibre (4.5 cN/dtex) is very much lower than the PVA fibre (13 cN/dtex) did not reflect a very large difference in flexural strength (MOR) between PET and PVA fibre cement products on the filter press method.

It should be pointed out however, that the levels of flexural strength values are rather low (5 MPa to 7 MPa). This is not normal for fibre cement products produced using this mix formulation. Therefore the flexural strength should be treated with caution and only a relative comparison between PET and PVA should be made for this purpose. Trends measured from 7 days to 28 days showed an increase in strength in general for all three products. This can be considered as relevant and the fact that no drop in flexural strength with time for PET products was found indicated that PET fibres were equally alkaline resistant to PVA using the same mix formulation and manufacturing conditions. The fact that this result in itself showed positive initial ageing properties for PET and PVA fibres, the idea to pursue the concept using PET fibres was found to be realistic.

Pilot Hatschek trials (stage 2)

For this investigation machine running conditions were monitored carefully and simulated the large scale Hatschek machine. Also as an additional evaluation, accelerated ageing tests were conducted after 28 days in order to test the potential alkaline attack on PET fibres. As a fair comparison PVA was used as a bench mark.

The flexural strength test results obtained from the products produced on the pilot Hatschek machine are given in table 4 below. These values are average values obtained from "width" and "across" directions in which the samples were tested. Products produced on a Hatschek machine have a preferred fibre alignment due to the running and process conditions of the Hatschek machine. It is standard practice to test samples in both orientations (width and across) and take the average value for general assessment purposes.

Table 4 - Flexural test values measured for products before and after accelerated ageing

		14 days	28 days	Accelerated Ageing
Flexural strength MPa	PVA	17.8	18.3	17.6
	PVA/PET	15.7	14.8	12.3
	PET	11.0	10.1	9.9
Fracture Energy kJ/mm^2	PVA	6.6	6.2	2.3
	PVA/PET	3.9	3.4	0.6
	PET	1.4	0.4	0.1

The results given in Table 4 would suggest that where comparing PVA with PET, the strength values for PET products are clearly lower than for PVA products and that the 50:50 mix of PVA/PET values lie between those of PVA products and PET products.

This is logical and to be expected considering the fibre tensile strength properties.

There appears to be a marginal increase in strength for PVA products from 14 days to 28 days and after this a slight drop in strength after accelerated ageing. For PET products and PVA/PET there is a trend for a reduction in strength from 14 days to 28 days and after accelerated ageing.

With regard to fracture energy (measure of the area under the stress/deflection curve); there is a predicted embrittlement of the product with age. This is well known for fibre cement products due to the increase in the interfacial (fibre/cement) bond and carbonation of the matrix. In order to understand this mechanism more closely, stress reflection curves are presented in figures 5 and 6.

For the purpose of interpretation the linear part of the stress / deflection curve is "pseudo elastic" behaviour of the material. When the stress deflection deviates from linearity, the first major crack is initiated in the product and at this point the fibre pull out / fracture occurs. After this the final stress to failure of the product is mainly a function of the fibre properties and the interfacial bond. The stress / deflection curves in figures 5 and 6 represent the preferred fibre orientation or machine direction (W/G). This is presented in order to emphasis the influence the fibre properties for interpretation purposes.

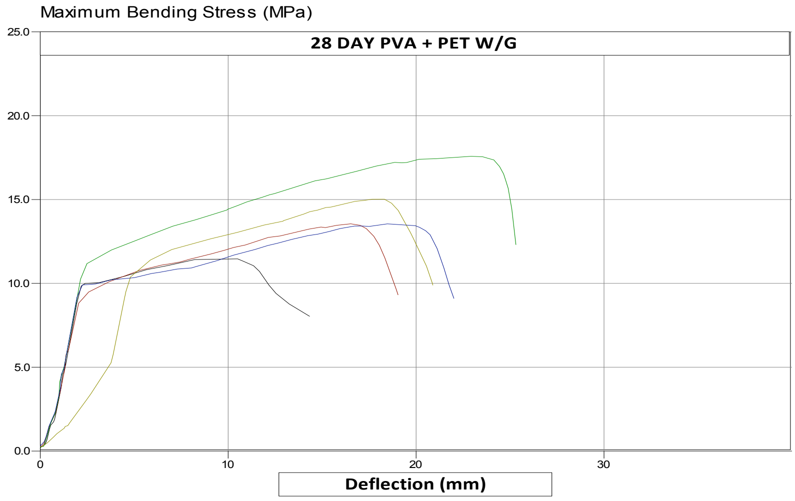
It can be seen from the curves given that a reduction in deflection to failure is clearly related to:

a) The age of the product
b) The type of fibre used

This may be interpreted as follows:

The bond between the PVA fibre and the matrix improves with age and secondly the bond between the PET fibre and the matrix is better than that of the PVA fibre. With age the PET fibre / matrix bond improves to such an extent that the product becomes very brittle with age and vertically no fibre pull-out is present with aged PET fibre cement products. The mix of PVA and PET fibres confirm this conclusion. It should be noted that there is a large scatter in the test results with aged PET fibre products. This could be related to bad PET fibre distribution during production. This was evident during production where fibre bundles were found to stick to each other without being dispersed. Therefor this trial will be repeated in order to confirm these preliminary results.

Figure 5: Stress / Deflection curves at 28 days



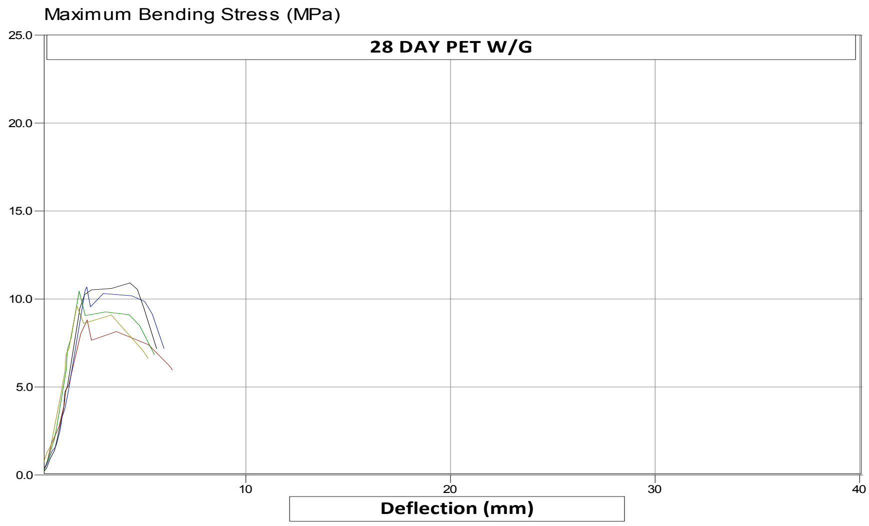
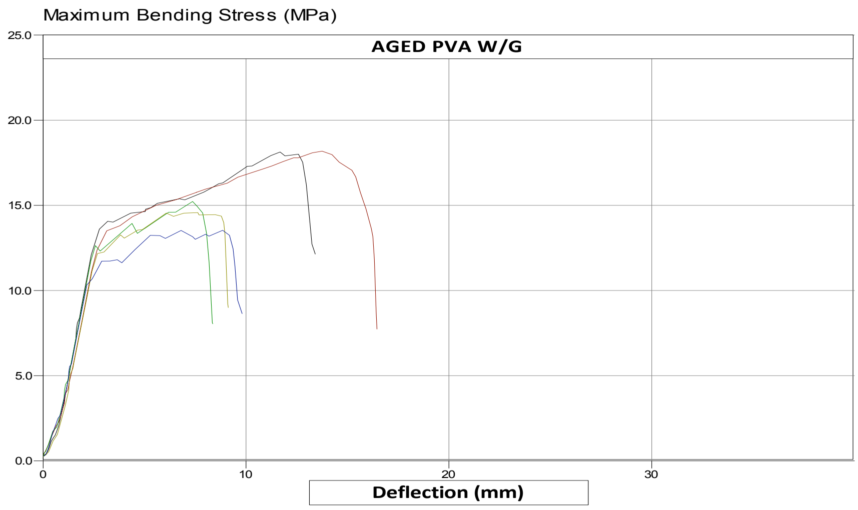
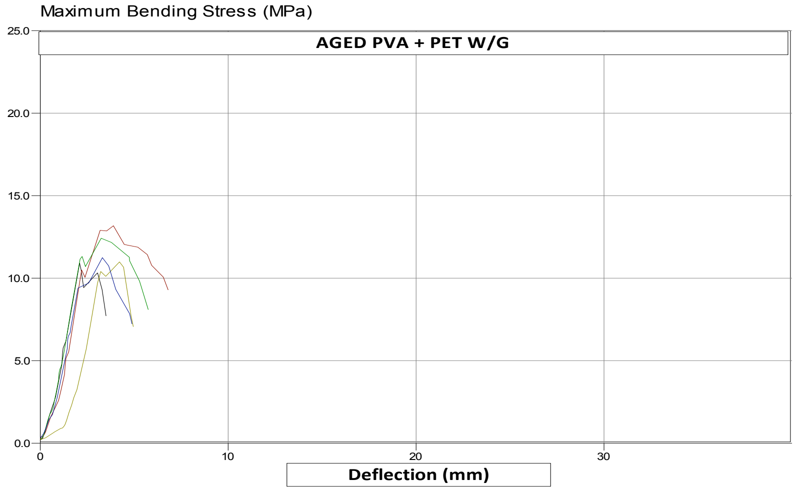
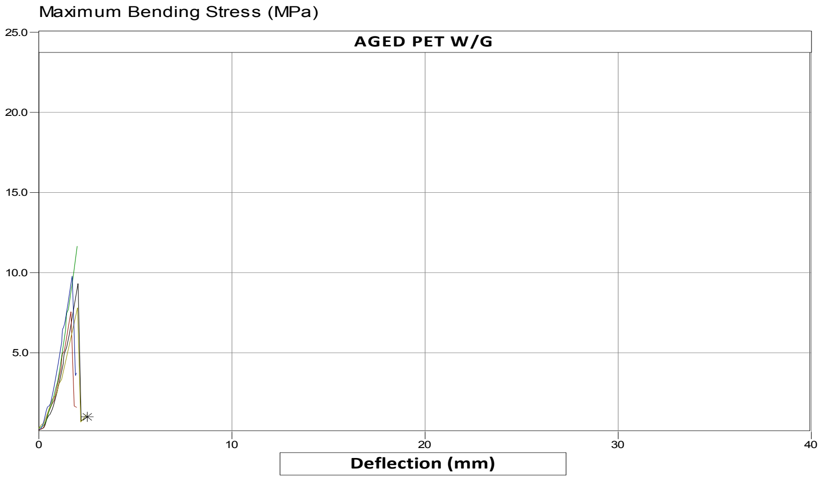


Figure 6: Stress / Deflection curves after accelerated ageing







PRELIMARY CONCLUSIONS AND FUTURE INVESTIGATIONS

- PET fibres show a good potential to be used in fibre cement products.
- The drop off in flexural strength with age in PET fibre cement products together with the associated embrittlement suggest that PET fibres are not equivalent to PVA fibres and therefore cannot be used as a direct replacement for PVA fibres.
- Hybrid mixes of PVA and PET fibres show potential and should be pursued further.
- The bad dispersion properties of PET fibres should be improved this can be done by adjusting the cutting blades during fibre production as the fibre bundles were fused at the ends for some of the fibres.
- Combination of PP and PET fibres should be investigated.
- Although there appears to be a drop off in strength with PET fibres with age, it should be noted that the residual strength remaining of the fibre after ageing, motivates further investigation, particularly from a cost / quality aspect.

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REFERENCES

Akers, S.A.S., Meier, P., Studinka, J.B., Dodd, M.G., Johnson, D.J., Hikasi, J. (1989) "Long term durability of PVA reinforcing fibres in a cement matrix". The international Journal of Cement Composites

Briggs, J., (2002) "European and International Cement and Concrete Materials Industry, A market / technology report". Materilas Technology Publications, Watford, UK, 124-125

De Lhoneux, B., Akers, S.A.S., Alderweireldt, L., Amiya, S., Carmeliet, J., Hikasi, J., Saenen, W., Studinka, J., Tomka, I., Vanden Bosch, M. (2002) "Durability study of PVA fibres in fibre cement products"., Proc., Ivth Int. Symp. Concrete for a sustainable agriculture N. De Belie & B., Sonck /Eds), 275-284

Martinola, G., Bäuml, M. F., (October 2002), "Optimizing ECC in order to prevent shrinkage cracking". Proceedings of the JCI Int. Workshop on Ductile Fiber Reinforced Cementitious Composites (DFRCC) 143