DURABILITY OF FIBRE-CEMENT ROOFING CORRUGATED SHEETS

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ABSTRACT

The durability of fibre-cement roofing sheets is in direct correlation with the type of fibres used, the structure of the matrix, and the curing conditions. This work is comprised of a study of the degradation of polyvinyl alcohol (PVA) and polyethylene terephthalate (PET) fibres in contact with a cement solution (pH~11.5); an evaluation of the methodology for accelerated aging test (200 soak & dry cycles) established by EN 494 (1994); and an evaluation of the influence of certain raw materials as well as natural weathering exposure on the appearance of edge cracks in fibre-cement roofing sheets produced by the Hatschek process and disposed in plastic wrapped piles. The results show that PET fibres presented degradation after approximately one month immersed in a cement solution and with a consequent tensile strength reduction of 53%. With respect to the parameters of the cycles of soaking and drying, the phenomena involved in the inlet and outlet water proved to be distinct from each other, with greater ease of absorption in comparison to drying out water. Corrugated sheets after 24 months of natural weathering exposure in rural area presented higher incidence of cracks on the north face of the stacked roofing sheets, while fibre cement sheets reinforced with PVA fibre and without silica fume in the matrix composition presented lower incidence of edge cracks when compared to other formulations evaluated in this work.

1 INTRODUCTION

The fibre cement industry produces cost-effective and functional building materials, which stand out in developed and developing countries, especially due to their versatility and easy manufacture.

Currently, the use of cellulosic fibres, especially through pulps, has considerable potential for application in fibre-cement production. They present several interesting advantages, in particular their low density, their bio-renewable character and their widespread availability at competitive cost and in a variety of morphologies and aspect ratios [1]. The pulps however are of such a length (2.5 to 3 mm) that they bridge the openings of the sieve and form an initial filter layer in the felt of the Hatschek machine. The Hatschek process is the most widely employed process in the production of fibre cement components [2]. The pulps form a film that blocks the sieve and allows for the capture of other cement and added mineral particles [3]. However, air cured cement composites only reinforced with natural fibres do not reach levels of mechanical performance with medium and long term reliability, mainly due to the degradation of cellulosic fibres in the alkaline environment [4]. One of the production methods to mitigate this drawback is the high pressure steam cured composites reinforced by cellulose fibres (autoclaved products), mainly for external cladding, sidings and internal partitioning as well as sealing [3].

At present times there is an alternative method for the production of roofing elements, usually for corrugated sheet, using traditional Hatschek technology [5]. This process is based on the use of air cured hybrid fibre-cement with refined wood pulp, such as pine and eucalyptus, and alkali-resistant synthetic fibres such as polyvinyl alcohol (PVA) and polypropylene (PP).

The textile type fibre, such as a reinforcement of polyethylene terephthalate (PET) high-performance yarn coated by resin, is recognized as an important synthetic construction material (high-tensile strength and excellent creep properties). However, its use presents challenges, such as a deterioration of mechanical properties and weak chemical stability (due to the hydrolysis of the PET ester group) [6].

Edge crack and delamination is another common phenomenon in air cured hybrid fibre-cement, which affects the finishing qualities of the roofing tiles. There is a lack of information about the effects and contribution of edge, or initial, cracks and delamination on the long-term and mechanical performance of theses composites produced by the air cured Hatschek process.

The main objective of this work is to present and discuss several variables involved with the degradation of fibre-cement corrugated sheets used for civil construction. Raw materials, processing and aging conditions will be evaluated in order to explain the several agents and mechanisms of decay of the asbestos free fibre cement composites. Consequently this paper presents a study of the degradation of polyvinyl alcohol (PVA) and polyethylene terephthalate (PET) fibres when in contact with a cement solution (pH~11,5); an evaluation of the methodology for accelerated aging testing (200 cycles) established by EN 494 (1994) [7]; and an evaluation of the influence of some raw materials and natural weathering exposure on the appearance of edge cracks in hybrid fibre-cement roofing tiles produced by the Hatschek process.

2 AGING TEST OF PVA AND PET FIBRES

The synthetic filaments are responsible for reinforcing, toughening and dimensional stability of the fibre-cement composite under utilization conditions during its service life. The chemical stability of these reinforcing elements in the cement environment is a key issue regarding the integrity and durability of the roofing corrugated sheets.

2.1 Materials and Method

The aging test of PVA and PET fibres immersed in saturated cement solution was carried out in the following conditions: 3 L of deionised water saturated with Portland cement CPV-ARI, 5 g of fibres, temperature 40ºC and pH ~11.5. The fibres were previously dispersed for 5 min at 3600 rpm. The fibres were analysed after 7, 21 and 35 days of immersion. The SEM images were performed using a Hitachi TM3000 microscope.

2.2 Results

This section presents SEM images, as well as the results for tensile stress of PET and PVA commercial fibres after performing the aging test in a saturated cement solution.

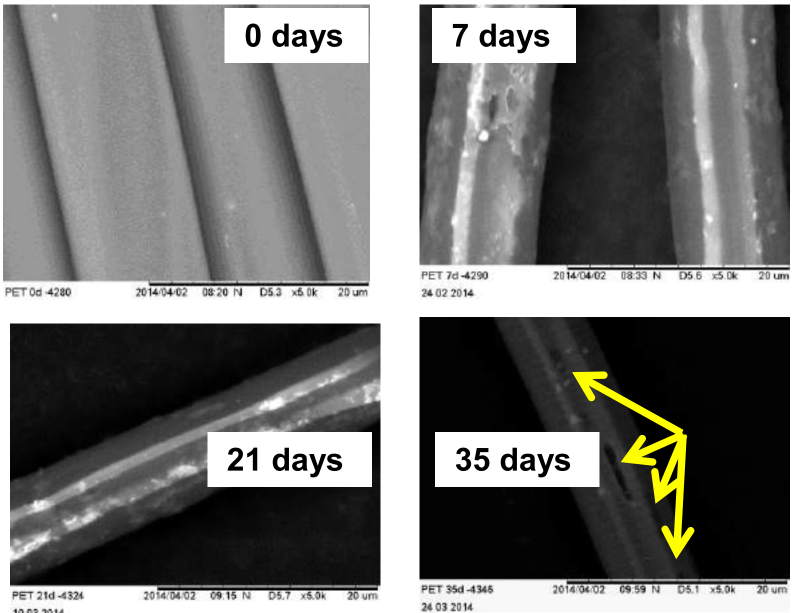


Figure 1: SEM Images of PET fibres exposed to saturated cement solutions by different periods of time.

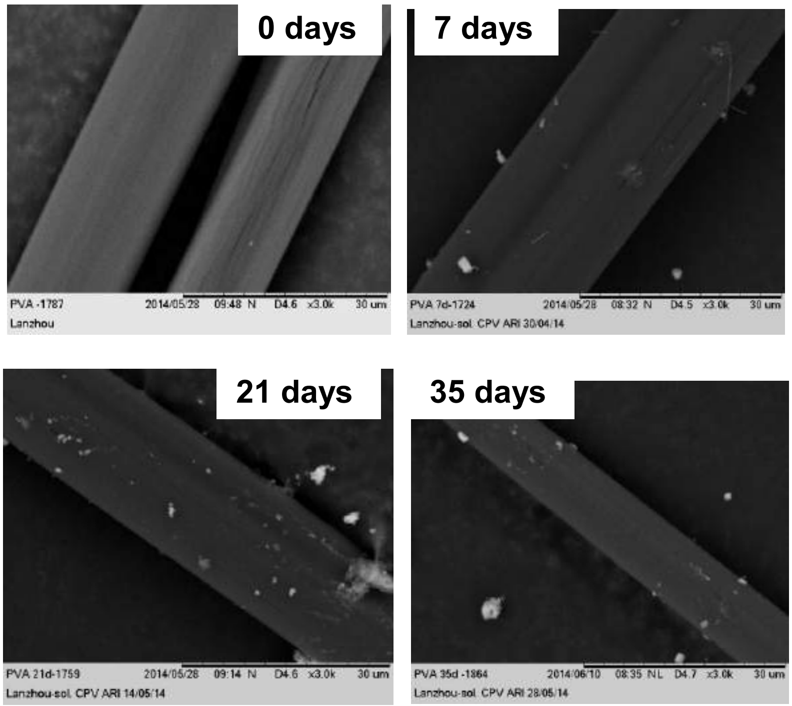


Figure 2: SEM Images of PVA fibres exposed to saturated cement solutions for different periods of time.

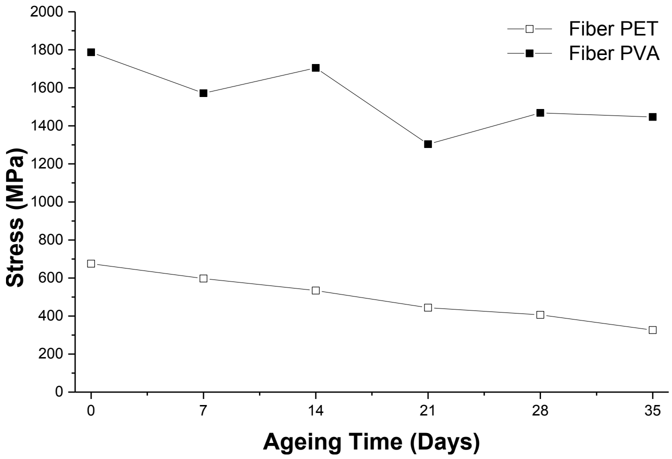


Figure 3: Evaluation of tensile stress: PET fibres and PVA fibres after different periods of exposition to severe alkaline attack.

After 35 days of immersion in saturated cement solution, degraded regions (holes) on the fibre surface and reduced fibre tensile strength of 52% were observed for the PET fibres (Figure 3). This behaviour is compatible with previous experiments carried out by Silva et al. [8] using PET recycled fibres in cement based materials with the consequent reduction of toughness of the studied mortars under aging conditions. For PVA fibres, the degradation of the surface of the fibre was not observed, however there was a reduction in the tensile strength of around 19% (statistically significant) but with a tendency of stabilization of mechanical strength after 21 days of exposition to the aggressive environment. These results indicate that the PET fibres under evaluation are not alkali resistant and their use in fibre-cement will possibly weaken the mechanical properties of the composites over time.

3 AGING TEST OF FIBRE-CEMENT ROOFING SHEETS

The accelerated aging test exposed the composite to cycles of immersion and drying in order to simulate the environmental conditions to which the material would be subjected in the actual applications.

3.1 Methodology

The procedure recommended by the International Standards [7] requires the completion of 50 soak & dry cycles. Each cycle is composed of immersion in a water tank at room temperature for 18 h and 6 h drying in a ventilated oven at 60°C. In this study the referred aging procedure was adapted, with respect to the period of duration of each cycle: approximately 3 h immersion and 3 h drying. The total number of cycles was also increased in the attempt to better characterize the behaviour of the different tested materials. This work adopted 200 ageing cycles (around 50 days of accelerated aging test) based on previous experience reported elsewhere [9,10].

To assess the composites behaviour submitted to the accelerated aging cycling, several formulations were sected with different reinforcing fibres: coir, PVA and cellulose pulp, mainly after 28 days of curing. Some of these composites were subjected to fast carbonation curing in the initial age as proposed by Almeida et al. [11].

3.2 Results

Dias [12] highlights the degradation mechanisms involved in the cycles of immersion and drying, such as alkali attack and densification of the fibre/matrix interface region.

Furthermore, the cited work refers to progressive damage caused to the material, which corresponds to the stresses generated by the dimensional movements during the thermal and hygroscopic cycles.

Table 1 shows the water absorption and water loss for the half cycle (2 h 50 min), and the maximum absorption and water loss observed for up to 9 h (540 min). Water absorption was observed to be faster and almost completed within 2 h and 50 min. Differently the carbonated materials only demonstrated 68% of the maximum water absorption during immersion what can be understood by the lower incidence of open capillary pores. The sealing generated by the carbonation reaction prevents the material from absorbing water during the course of 2 h and 50 min, but the same is not true for the other treatments. This refinement of the pore structure and limited access of water to the fibrous composite may explain the lower shrinkage of the carbonated material before and after 200 aging cycles (Figure 4).

With respect to the loss of water during drying process (Table 1), it was observed that the loss water movement takes longer for all the analysed treatments what would determine greater periods (even longer than 9 h) for loosing higher amount of free water. The carbonated material, following the previous result of absorption, also showed the lowest relative loss compared to non-carbonated materials.

Table 1. Water absorption/loss average numbers of different composites in one cycle of the soak & dry test

Treatments **Curing - reinforcing fibre**	**Water absorption (%)**		**Relation (%)[1]**
	170 min	**540 min**	
Carbonated - cellulose pulp	6.28	9.22	68
Non-carbonated - cellulose pulp	16.13	16.83	96
Non-carbonated - PVA fibre	19.27	19.53	99
Non-carbonated - coir fibre	18.28	18.73	98
Treatments **Curing - reinforcing fibre**	**Water loss (%)**		**Relation (%)[1]**
	170 min	**540 min**	
Carbonated - cellulose pulp	3.96	7.94	50
Non-carbonated - cellulose pulp	7.35	11.53	64
Non-carbonated - PVA fibre	10.94	14.16	77
Non-carbonated - coir fibre	10.82	14.20	76

[1]Water absorption/loss after 170 min in relation to 540 min.

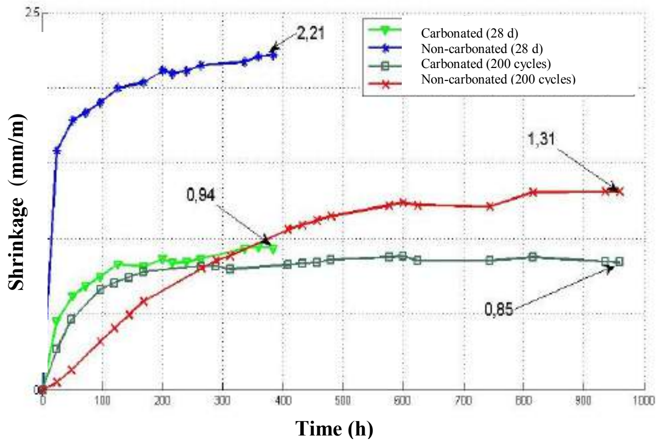


Figure 4: Variation on drying shrinkage composite over time.

4 EDGE CRACKING OF FIBRE-CEMENT CORRUGATED ROOFING SHEETS

Edge cracking is a serious pathology that commonly affects air cured fibre cement materials during drying conditions when the corrugated sheet are still in piles. It is normally generated in the initial ages by the stresses that take place when the water evaporation in the lateral edge of the sheet stack is faster that the internal diffusion of the water in the pile.

4.1 Materials and Method

The roofing sheets evaluated in the study were industrially produced by the Hatschek process and were composed of: polymeric fibres, PVA and/or PP, refined bleached pine pulp, refined unbleached eucalyptus pulp, Portland cement, silica fume and limestone. The fibre-cement roofing sheets after were submitted to ten days of saturated curing and subsequently to 24 months of natural weathering exposure in a rural environment located in Pirassununga, São Paulo state, Brazil (21^{o} 59'S latitude and 627 m of altitude). The roofing sheet piles were oriented with coverage wave positioned to the magnetic north and waiting wave to the south for the maximum incidence of solar radiation in the critical face of the pile (for the south hemisphere). All piles were packed with transparent plastic for the 24 months of analysis, in order to avoid excessive evaporation of water to the environment and simulating the real conditions of sheet stacks in the storage conditions. Table 2 lists the treatments studied, according to the formulations containing different types of plastic fibres (PVA and/or PP).

Table 2. Formulations of the roofing sheets submitted to edge-cracking study

Treatment	Formulation (fibre + pozzolan adition)	Treatment	Formulation (fibre + pozzolan adition)
T1	PVA+ silica fume	T4	PP
T2	PVA	T5	PVA+PP+ silica fume
T3	PP+ silica fume	T6	PVA + PP

The study of edge cracks and delamination was performed by means of a visual analysis in order to observe the magnitude, positioning in the sheet edge/stack and number of defects detected. The lateral faces of the piles of fibre-cement sheets were divided into nine sections to facilitate the identification and the quantification of the incidence of edge cracks and delamination. The percentage of cracked roofing sheets was calculated dividing the number of cracked sheets by the total number of sheets in the piles. The analyses were performed at 28 days and 2, 6, 12 and 24 months after production.

4.2 Results

Table 3 shows that the lateral side of the sheet stacks facing north generally yielded the highest percentage of edge cracking, regardless of the formulation (T1-T6). These results suggest a direct relationship between severity of the natural weathering exposure such as higher temperatures (average temperature > 25^{o}C) which maximise the rate of water loss, and the corresponding shrinkage of the material with the consequent stress-induced edge cracking. The increased diffusion and evaporation of water in the region close to the stack edge, when compared with the central zone of the pile results in a significant moisture gradient and with the preponderant stress factor across the edge of the corrugated sheets. No edge crack propagation to the centre of the roofing sheets was noted without compromise to the tightness or mechanical performance. Furthermore, there was no identification of significant incidence of delamination in the roofing sheets under analysis.

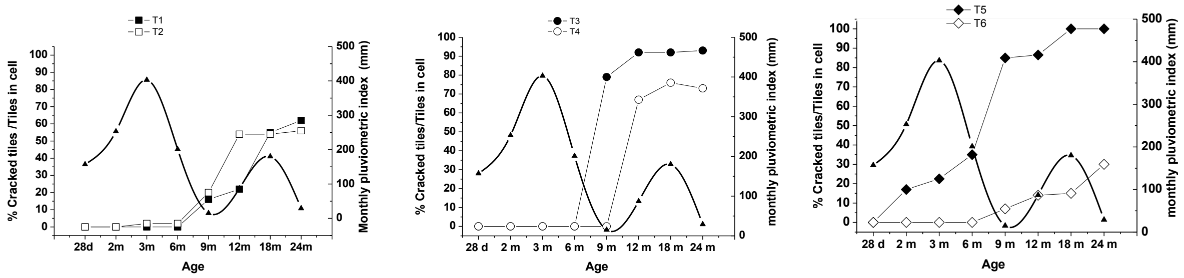
Table 3. Proportion (%) of cracked roofing sheets on north (N) and south (S) faces - different ages

Age / Face	**T1**		**T2**		**T3**		**T4**		**T5**		**T6**	
	N	**S**	**N**	**S**	**N**	**S**	**N**	**S**	**N**	**S**	**N**	**S**
28 d	0	0	0	0	0	0	0	0	0	0	0	0
2 m	0	0	0	0	0	0	0	0	17	17	0	0
6 m	0	0	2	29	0	7	0	06	35	36	0	1
12 m	22	4	54	30	92	9	67	18	87	42	14	2
24 m	62	70	56	30	93	13	73	22	100	42	30	22

Legend - d: days; m: moths; N: North; S: South

Table 3 highlights the T1 and T2 formulations' superior resistance against edge cracking after the natural weathering exposure period, i.e. fibre cement roofing sheets reinforced with PVA fibres, with and without silica fume, presented less edge cracks on the north face of the piles than other formulations. There was no significant contribution of silica fume to the reduction in edge cracking in the roofing sheets for the observed formulations.

Figure 5 depicts the results of edge cracks on the north face of the piles and the rainfall index for different periods. The existence of a correlation between the number of edge cracks in the piles and a low rainfall index (winter season) was observed. Periods of lower relative humidity exert an increase in the rate of water loss of the roofing sheets, resulting in the occurrence of edge cracks. However, it was also noted that for formulations T1 to T6, the incidence of edge cracks was less than 40%, during the 6 month summer period, characterized by the high rainfall indexes.



(a) (b) (c)

Figure 5: Rainfall index (▲) and the proportion of sheets in piles with edge cracks in different ages (a: T1 – T2; b: T3 - T4; c: T5 - T6).

FINAL REMARKS

The durability of asbestos free air cured fibre cement material is resultant of several variables related to raw materials, curing procedures and weather exposition. Accelerated tests also are limited to reproduce the absorption/loss of water movement. The PET filaments show a much greater reduction in the reinforcing capacity in comparison to PVA fibre exposed to the alkaline cementitious environment. Fast carbonation curing contributes for the reduction of water movement and with the consequent dimensional stability of the fibre cement.

The edge cracks of the fibre cement roofing sheets disposed in piles showed a consistent evolution after 24 months of natural weathering exposure. Fibre cement sheets reinforced with PVA fibres, with and without silica fume addition in the cement matrix, presented lower percentage of edge cracks on the north face than other formulations.

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