DEVELOPMENT OF HYBRID FIBRE-CEMENT CORRUGATED SHEETS: A CASE STUDY OF EDGE CRACKS

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ABSTRACT

This experiment investigates systematically the occurrence of edge cracks in the piles of fibre cement corrugated sheets due to stresses generated in the long term during the free water evaporation and the consequent dimensional variation suffered by the stacked sheets before their definitive installation on a roofing structure. This work presents a case study evaluating the influence of some raw materials applied in the composite formulation and natural weathering exposure on the occurrence of edge cracks in the hybrid fibre-cement corrugated sheets produced by the Hatschek process. This work evaluated approximately 1200 hybrid fibre cement roofing sheets in different formulations with polyvinyl alcohol (PVA) and polypropylene (PP) fibres, as well as the combination of the two fibres, with and without silica fume. The hybrid fibre cement corrugated sheets were submitted to over 24 months of natural weathering exposure simulating the behaviour of stockpiles in the rural environment in the State of São Paulo, Brazil. The results show that the highest incidence of cracks occurs on the covering wave of the corrugated sheet pile after 9 months of weather exposure. However, fibre cement sheets reinforced with PVA fibre and without silica fume exhibited less edge cracks compared to other formulations evaluated in this work. Consequently, it was observed that the contribution of silica fume in some of the cement matrices remained inconclusive. It was also found that edge cracks do not have a significant effect on the flexural behaviour of the hybrid fibre cement roofing tiles.

KEYWORDS:

Roofing sheets, polyvinyl alcohol fibres, polypropylene fibres, cellulosic pulp.

INTRODUCTION

The fibre cement industry produces cost-effective and functional building materials, which stand out in developed and developing countries, by their versatility and practicality of manufacture.

Currently, the use of cellulosic fibres, especially the pulps has considerable usage in fibre-cement production. They present several interesting advantages particularly regarding their low density, bio-renewable character and availability at relatively modest cost and in a variety of morphologies and aspect ratios (Tonoli et al., 2009). The pulps however are of such a length (2.5 to 3 mm) that they bridge the openings of the rotary sieve in the Hatschek Machine[1] vats forming an initial filter layer (Figure 1) that allows for the capture of other cement and mineral addition particles (Cooke, 2000). However, air cured cement composites reinforced only with natural fibres do not reach levels of mechanical performance reliable in medium and long term, due mainly to the chemical degradation of cellulosic fibres (Mohr et al, 2007). One of the production routes to mitigate this drawback includes steam cured products reinforced by cellulose fibres (autoclaved products), mainly for external cladding and internal partitioning and ceiling (Cooke, 2000).

[1] The Hatschek process is the most widely employed process in producing fiber cement elements (Dias et al., 2008).

Another production route is based on air cured hybrid fibre-cement with refined wood cellulose pulp, such as pine and eucalyptus, and alkali-resistant synthetic fibres such as polyvinyl alcohol (PVA) and polypropylene (PP) for the production of corrugated sheet, based on the traditional Hatschek technology (Ikai et al., 2008).

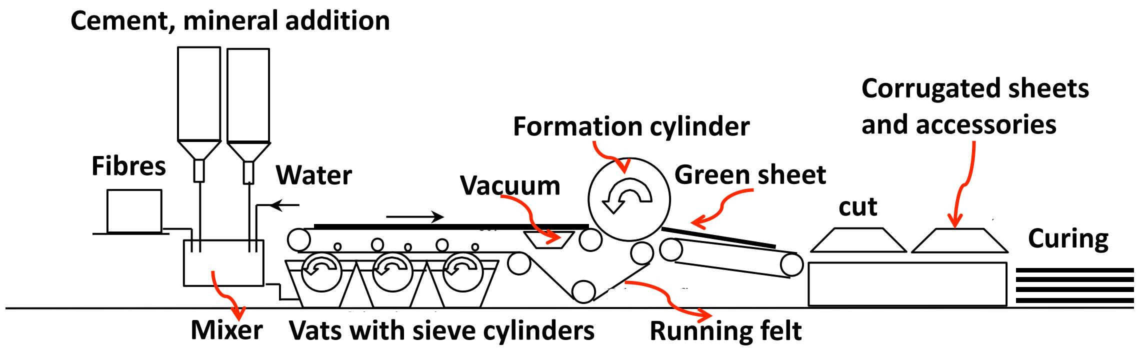

Figure 1 - Schematic drawing of the typical air cured Hatschek process (adapted from Dias et al, 2008).

Edge crack and delamination is a common problem in air cured hybrid fibre-cement, which affects the finished quality of the corrugated sheets. However, there is a lack of information about the effects of the edge cracks or initial cracks and delamination on the long-term and mechanical performance of theses composites produced by the air cured Hatschek process. This paper presents a study of the durability of fibre-cement roofing sheets subjected to natural aging during 24 months in a tropical weather. The present study evaluated the evolution of the edge cracks and delamination of hybrid fibre-cement roofing tiles produced by the Hatschek process with different formulations: polyvinyl alcohol (PVA) and polypropylene (PP) fibres, as well as the combination of the two fibres and with and without the addition of silica fume.

MATERIALS AND METHODS

The roofing sheets with 5 mm of thickness were industrially produced by the Hatschek process and had the composition of polymeric PVA and/or PP fibres, refined unbleached Pinus pulps, refined bleached eucalyptus pulp, Portland cement, silica fume and ground limestone. The hybrid fibre-cement roofing sheets after ten days of air curing were submitted to over 24 months of natural weathering exposure in rural area located in Pirassununga, São Paulo state, Brazil (21° 59'S latitude and 627 m altitude). The area where the roofing sheets were placed was stable and simulated a severe condition of exposition of stacked sheets in an unprotected stock place before installed on a roof. The analyses were performed at 28 days, and also at 2, 3, 6, 9, 12, 18 and 24 months after production. Although this time range up to two years could be considered unrealistic for usual commercialization of construction materials, the main idea of the experimental work was to understand the behaviour of the visible edge cracks in the pile and the mechanical behaviour of the corrugated sheets after exposition under the referred conditions in the long term.

Figure 2a presents the fibre-cement roof sheets studied in the experimental field. Piles of roof sheets were oriented with coverage wave facing north (which implies the highest incidence of solar radiation in the southern hemisphere) and consequently with the waiting wave facing to the south (Fig. 2b). All piles were packed with transparent plastic film during the 24 months of analysis, in order to avoid excessive loss of water rate by evaporation. Table 1 lists the different treatments under evaluation.

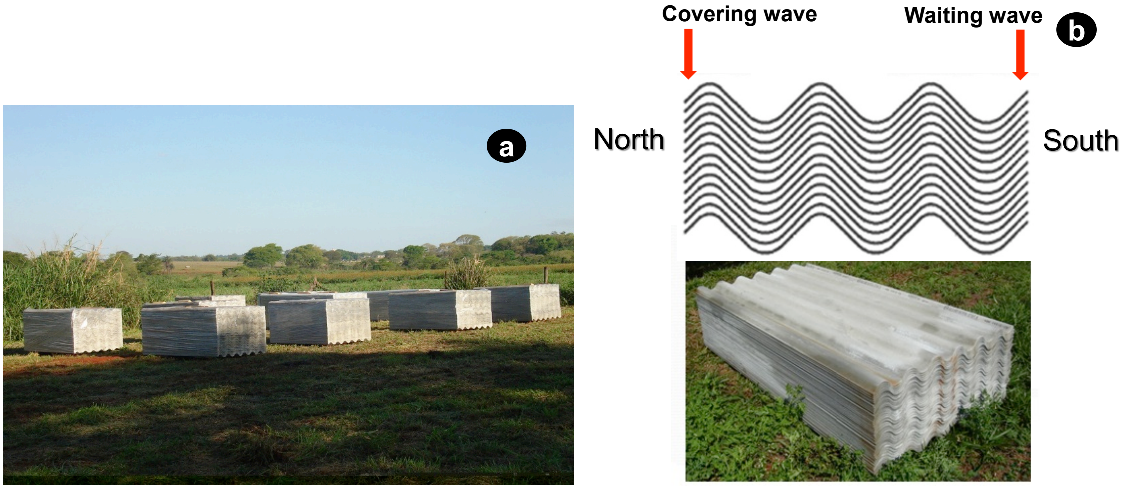

Figure 2 – (a) Roofing sheets exposed in the experimental field, (b) position of the piles of the roofing sheets in the experimental field.

Table 1 – Treatments with different reinforcing fibres and with/without silica fume addition

Treatment	Formulation
T1	PVA+ silica fume
T2	PVA
T3	PP+ silica fume
T4	PP
T5	PVA+PP+ silica fume
T6	PVA + PP

The size, position and number of edge cracks and delamination were determined by means of a visual analysis. The percentage of cracked roofing tiles was calculated by dividing the number of tiles cracked by the number of tiles in each pile. After the visual analysis, four sheets were removed from the upper part of the piles and submitted to the three-point bending load test, according to the Brazilian standard ABNT– NBR 15210-2:2005.

RESULTS AND DISCUSSION

Figure 3 shows typical edge cracks (with 0.5 – 1.0 mm of thickness and 20-30 mm of length) in the pile of the roof sheets. Table 2 shows a higher incidence of edge cracks in the sheet piles on the covering waves facing north for all the formulations under evaluation (T1-T6). The results suggest that the exposure to higher temperatures (average temperature > 25^{o}C), maximizes the rate of water evaporation and, consequently, increases the shrinkage as a stress-induced edge crack. The increased loss of water in the edge of the sheet pile as compared with the central portion of the pile results in the significant moisture gradients and tensile stress over the edge of the sheet. Besides, significant incidence of delamination in the roofing sheets was not identified.

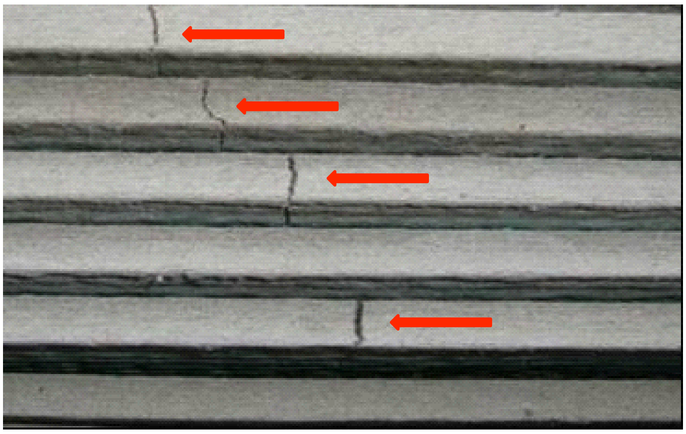

Figure 3 – Arrows show typical edge cracks in the covering wave of the roof sheet.

Table 2 – Incidence (%) of edge cracks in the covering wave facing north (N) and waiting wave facing south (S) of roof sheet piles at different ages.

Age	T1 PVA+SF		T2 PVA		T3 PP+SF		T4 PP		T5 PVA+PP+SF		T6 PVA+PP	
	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
3 m	0	0	2	8	0	5	0	5	23	34	0	1
6 m	0	0	2	29	0	7	0	6	35	36	0	1
9 m	16	0	20	29	79	7	0	8	85	42	7	1
12 m	22	4	54	30	92	9	67	18	87	42	14	2
18 m	55	70	54	30	92	12	76	22	100	42	15	7
24 m	62	70	56	30	93	13	73	22	100	42	30	22

Legend: PVA and PP: synthetic fibres; SF = silica fume; d: days; m: months; N: North; S: South.

Figures 4 to 6 show the occurrence of edge cracks in the north face of the sheet pile. The hybrid fibre cement roof sheets reinforced with PVA fibres, with and without addition of silica fume in the cement matrix, exhibited lower incidence of edge cracks in the north face of the sheet pile than other formulations. It is possible to observe the increase in the amount of edge cracks in the north face of the pile sheet after 9 months of weather exposure. Based on the present results of the treatments T1 and T2 the contribution of silica fume in the cement matrix remained inconclusive in the long term (after one year of exposition). However, for the mix designs with PP fibres (T3 and T4) the addition of silica fume (SF) in the matrix seemed to be effective to reduce the incidence of edge cracks in the north face of the pile for ages up to 6 months.

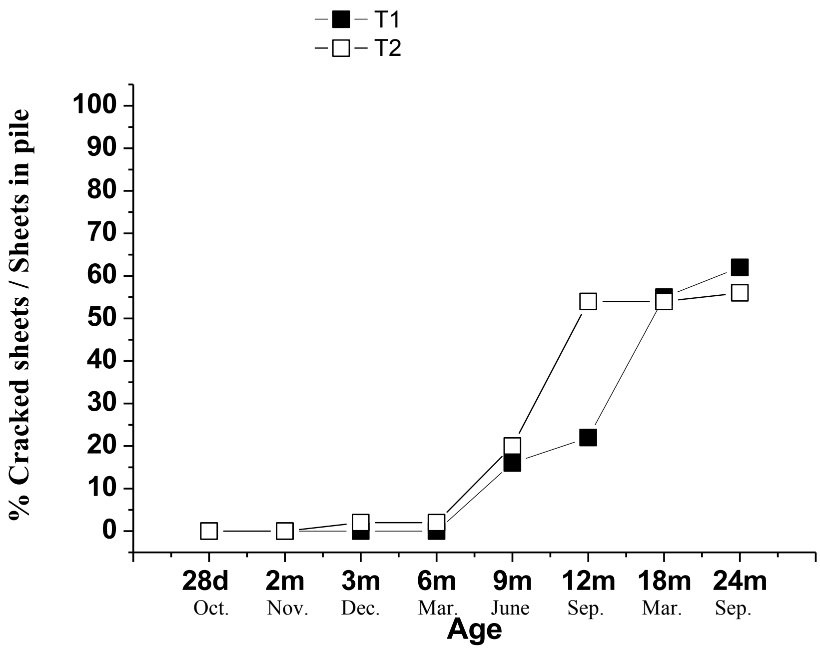

Figure 4 – Evolution of the incidence (%) of edge cracks in the T1 (PVA+SF) and T2 (PVA) sheet piles during the weather exposition.

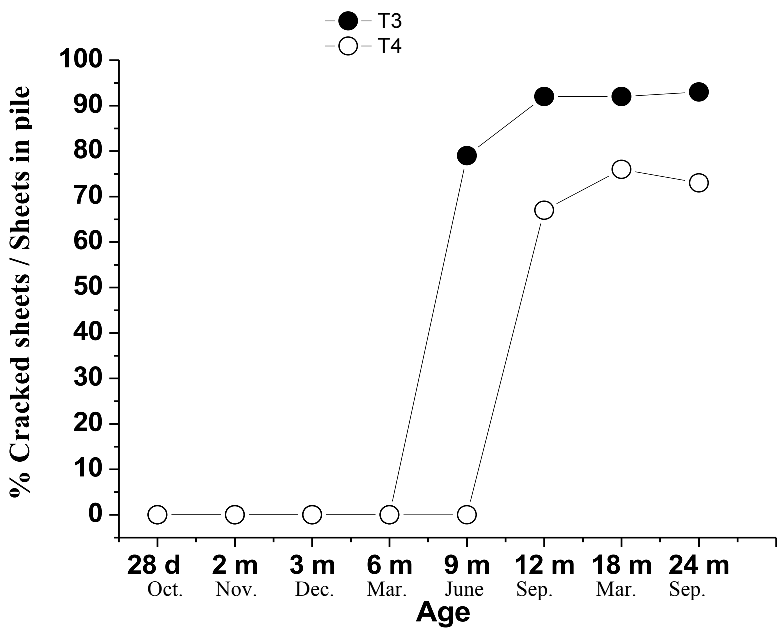

Figure 5 – Evolution of the incidence (%) of edge cracks in the T3 (PP+SF) and T4 (PP) sheet piles during the weather exposition.

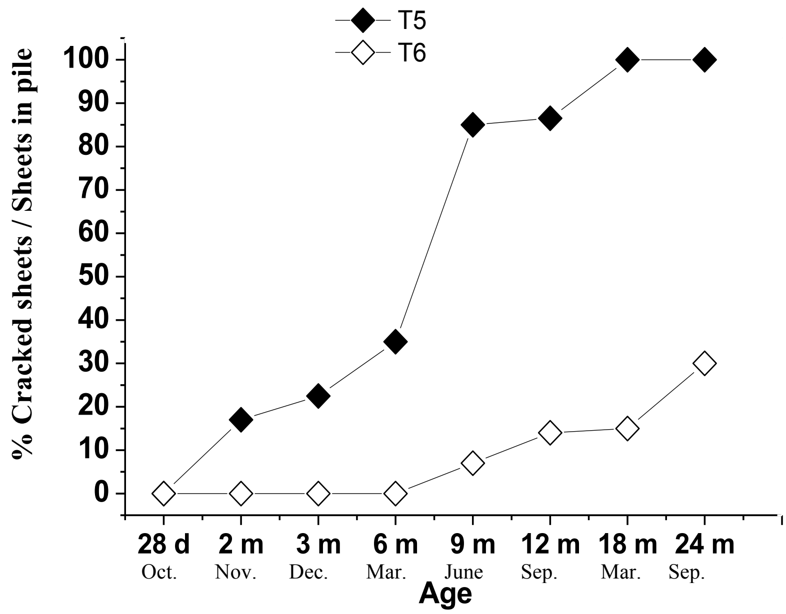

Figure 6 – Comparison between the incidence (%) of edge cracks in the T5 (PVA+PP+SF) and T6 (PVA+SF) sheet piles during the weather exposition.

Figure 7 shows average results and corresponding +/- standard deviation bars for the maximum load per meter of the hybrid fibre cements corrugated sheets (T1 to T6). The results of the maximum load indicate that no significant variations in the mechanical performance of the corrugated sheet for the T1 to T6 formulations over the 24 months of natural weathering exposure. Even with the increase in the amount of edge cracks in the north face of the pile sheet after 9 months of weather exposition, the mechanical performance of the corrugated sheets remains above 2500 N/m, according to the Brazilian Standards NBR 15210-2:2005 for roofing sheets with 5 mm of thickness.

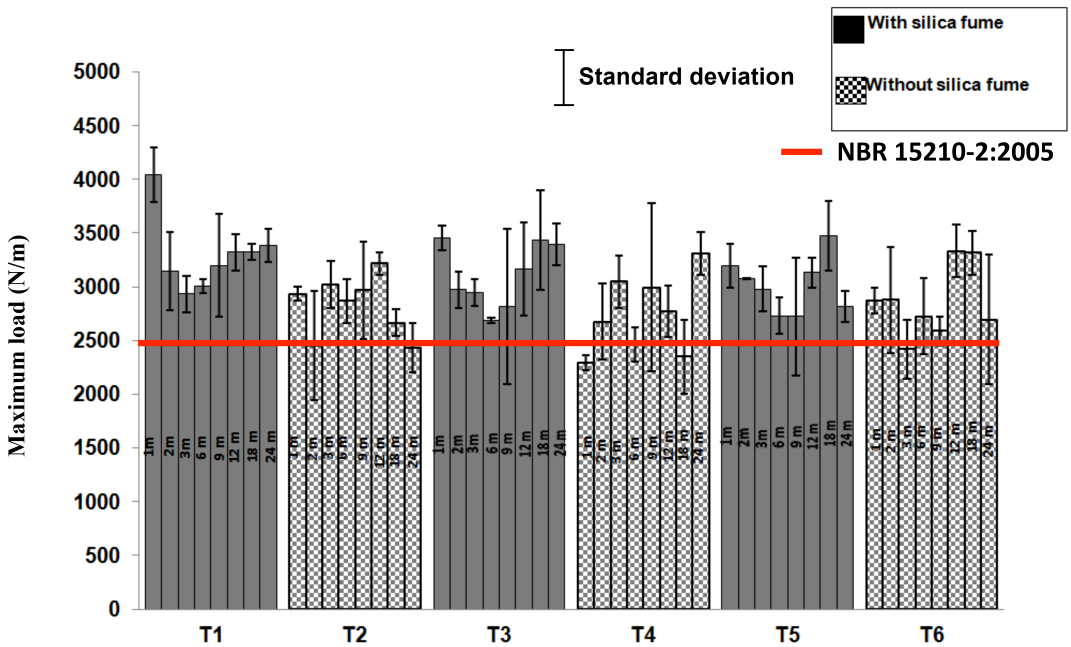

Figure 7 – Load per meter for different treatments and ages (*m: month).

The results of this study show an interesting approach to evaluate edge cracks of the fibre-cement corrugated sheets. These findings show that it is possible to manage the formulation in order to delay or even eliminate the appearance of edge cracks and thus overcome the problems associated with the incidence of these edge cracks in stacks exposed to natural conditions.

CONCLUSION

The idealized case study observed and measured the evolution of the edge-cracks in roofing sheets under direct exposure to tropical climate in plastic wrapped stacks. There was a greater occurrence of edge cracks located in the north face of the sheet piles which can be understood by the higher incidence of solar radiation (in the case of South Hemisphere) and with the consequent stresses generated by the water evaporation in the stacked piles of corrugated sheets. The contribution of silica fume in the formulation of the cement based matrix with PVA fibres for the reduction of edge cracking in the sheet piles is inconclusive based on present results. However, for the mix designs with PP fibres, the addition of silica fume (SF) in the matrix seemed to be effective to reduce the incidence of edge cracks in the north face of the sheet pile for ages up to 6 months of exposure. Corrugated sheets reinforced with PVA fibres presented lower incidence of edge cracks in the covering waves facing north in comparison to the other formulations. It is possible to observe the increase in the amount of edge cracks in the north face of the pile sheet after 9 months of weather exposition which can be associated to the drying process of the stacked sheets according to the weather conditions. The increase on edge cracking did not interfere in the mechanical behaviour of the corrugated sheets with 5 mm of thickness, as the results of bending test indicated maximum loads in excess of 2500 N/m, as specified by the Brazilian Standards, indicating the good performance of the roof sheets even after 24 months of exposition to tropical Brazilian weather.

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