November 8th – 11th 2016, Fuzhou Empark Exhibition Grand Hotel, Fuzhou, China

Paper #15

FIBRE-CEMENT CORRUGATE SHEETS WITH PVA AND PET SYNTHETIC FIBRES FOR ROOFING APPLICATIONS

JULIANO, FIORELLI[1]; ZAQUEU, DIAS DE FEITAS[1]; GUSTAVO, ROCHA DE PAULA[2], HOLMER, SAVASTANO JUNIOR[1]

[1] *University of São Paulo, Av. Duque de Caxias Norte, 225. Pirassununga - Brazil*

[2] *INFIBRA, Leme – Brazil*

ABSTRACT

Fibre-cement corrugate sheets reinforced with cellulose pulp and synthetic fibres have increased exponentially in recent years in developing countries such as Brazil. The use of new synthetic fibres that have lower costs and higher performances is a challenge to be met. This work presents the physical-mechanical properties of fibre cement sheets produced in Hatschek machines. The aim of this work is to evaluate the performance of those composites produced with different kinds of synthetic fibres, polyvinyl alcohol (PVA) as the only fibre, and hybrid composite based on 85% of polyvinyl alcohol (PVA) and 15% of polyethylene terephthalate (PET) fibres. The samples were evaluated before and after accelerated aging test (soaking and drying) and also after 7 months of exposure in natural weathering. The tests were realized with recommendations of RILEM (Testing Methods for Fibre Reinforced Cement-Based a Composites) and Brazilian Standard (NBR 15210:2014 – Fibres-Cement Corrugate sheets without asbestos and its accessories). The results indicated that samples with 15% of PET fibres don't have significant statistical difference in physical properties (bulk density, water absorption and porosity) when compared with samples containing 100% PVA fibre before and after accelerated aging test. However, the mechanical properties presented significant statistical difference with a 12% reduction in the modulus of rupture and after accelerated aging test a 18% reduction in the modulus of rupture of samples with PET fibres. The corrugated sheets with PVA and PET fibres presented rupture load before and after natural weathering above the minimum recommended (2500 N/m) by the Brazilian Standards NBR 15210:2014. The physical-mechanical characterizations suggest an acceptable performance of the fibre cement sheets with PVA and PET fibres.

KEYWORDS:

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

INTRODUCTION

Fibre-cement corrugate sheets reinforced with cellulose pulp and synthetic fibres have increased exponentially in recent years in developing countries such as Brazil. The use of new synthetic fibres that have lower costs and higher performances is a challenge to be met.

Investigations into synthetic fibres for applications in cement composites have focused on polyvinyl-alcohol (PVA) fibres, which are commonly used in high performance fibre reinforced cementitious composites, strain hardening cementitious composite (SHCC) or Engineered Cementitious Composite (ECC) applications (Lepech et al., 2008 and Li et al., 2002). PVA reinforced composites exhibit excellent mechanical properties, but at relative high cost (Li et al., 2001).

The textile polyethylene terephthalate (PET) high-performance yarn coated with materials, such as polyvinyl chloride (PVC) or acrylic resins, has high-tensile strength and excellent creep properties. However, its use has problems, such as a decrease in mechanical properties and the ease with which it is externally damaged due to its relatively weak chemical stability and the hydrolysis of the PET ester group (Cassidy and Mores, 1992 and Koerner, Lord and Hsuan, 1992).

It is well known that a decrease of physical and mechanical performance occurs when recycled PET fibres are applied in the cement based construction material (Silva et al., 2005). Particularly, as a reinforcement fibre in contact with high alkaline compounds eluted from cement based components, it may be chemically degraded because of exposure to rain or surface water (Jeona et al., 2005).

This work presents the physical and mechanical properties of fibre cement sheets produced in Hatschek machines in the industrial scale. The aim of this work is to evaluate the performance of these composites produced with different types of synthetic fibres, polyvinyl alcohol (PVA) as the only fibre, and hybrid composite based on 85% of polyvinyl alcohol (PVA) and 15% of polyethylene terephthalate (PET) fibres.

MATERIALS AND METHODS

The experimental study assessed samples with dimensions of 160 x 30 mm taken from the corrugated sheets with a thickness of 5 mm and large waves produced industrially by the Hatschek process with (a) 100% PVA synthetic fibres (dtex 2.03) in mass and (b) 85% PVA fibres combined with 15% PET fibres (dtex 1.50) in mass. The evaluation of the samples took place after two distinct exposure situations:

- 10 days of conventional air curing and after exposure to accelerated aging test or.
- 10 days of controlled curing upon exposure to air in protected environment (laboratory conditions) and after natural aging test of 7 months, exposure to external environment in tropical weathering.

Accelerated aging test

An automatic soaking drying Marconi Model MA 035 was used for the accelerated aging test. Samples were introduced into the automatic soaking in the parallel direction to the air flow and subjected to 200 cycles of immersion-drying. The cycles correspond to 2 h and 50 min at a temperature of 60°C with air circulation (drying) over 2 h and 50 min immersed in water at room temperature (soaking), and between each stage there is an interval of 10 min, with a total of 6 h each cycle.

Natural aging test

The experimental site selected for the natural aging test was a flat concrete slab, providing perfect accommodation of 100 corrugated sheets packed with a film plastic to protect the products. Those corrugated sheets were exposed for 7 months during the tropical summer season with average temperature of 25°C and pluviometry index of 1200 mm.

Physical and mechanical tests

The determination of water absorption, bulk density and porosity of the flat samples extracted from the corrugated sheets produced with PVA fibres and PVA + PET fibres followed the recommendations of ASTM C-948-81 (Standard test method for dry and wet bulk density, water absorption and apparent porosity of thin sections of glass-fibre reinforced concrete). The mechanical properties were determined by flexural strength test based on the RILEM recommendations (Testing Methods for Fibre Reinforced Cement-Based Composites). For this test it was used an Universal Testing Machine (EMIC - model DL 30000) and load cell with capacity of 1 kN. Prior to testing, the specimens were immersed in water for 24 h at room temperature.

The corrugated sheets were mechanically evaluated by flexural strength test following the recommendations of NBR 15210-2 (Corrugated sheets cement asbestos and their accessories. Part 2: Testing). For this test it was used an Universal Testing Machine (Chin – model WDW-20E) and load cell of 20 kN capacity. The ABNT NBR 15210-1 Brazilian Standards specify that the minimum bending load should be 2500 N/m to corrugated sheets with 5 mm of thickness (class B). Prior to testing, the composite sample was immersed in water for 24 h at room temperature.

RESULTS

Flat samples extracted from the corrugated sheets

Tables 1 and 2 show the average values and standard deviation of bulk density, water absorption and apparent porosity of flat samples extracted from the corrugated sheets with PVA fibres and PVA + PET, before and after the accelerated aging test (200 soak & dry cycles). An inferential statistical analysis comparing the experimental values by a Tukey test, with a 5% significance level is presented.

The results indicate that there is no statistically significant difference ($p > 0.05$) between PVA and PVA + PET formulations in identical conditions before and after exposure to accelerated aging (200 cycles) for the evaluated physical properties.

Table 1 – Physical properties of flat samples extracted from the corrugated sheets before the aging test

Fibres	Bulk Density ($g.cm^{-3}$)	Water absorption (%w/w)	Apparent porosity (%v/v)
PVA	1.55 ± 0.01 **a**	24.63 ± 0.34 **a**	38.17 ± 0.29 **a**
PVA + PET	1.57 ± 0.01 **a**	24.32 ± 0.33 **a**	38.10 ± 0.28 **a**

* Different letters in same column represent statistically significant difference ($p < 0.05$)

Table 2 - Physical properties of flat samples extracted from the corrugated sheets after the aging test

Fibres	Bulk Density ($g.cm^{-3}$)	Water absorption (%w/w)	Apparent porosity (%v/v)
PVA	1.55 ± 0.02 **a**	24.03 ± 0.31 **a**	37.34 ± 0.51 **a**
PVA + PET	1.58 ± 0.02 **a**	23.88 ± 0.84 **a**	37.65 ± 1.16 **a**

* Different letters in same column represent statistically significant difference ($p < 0.05$)

Tables 3 and 4 show average values and standard deviation in bending test of Modulus of Rupture (MOR), Limit of Proportionality (LOP), Modulus of Elasticity (MOE) and Specific Energy (SE) of the flat samples extracted from the corrugated sheets reinforced with PVA fibres or PVA + PET fibre in conditions without aging and after accelerated aging test (200 cycles). An inferential statistical analysis comparing the experimental values by the Tukey test, with a 5% significance level is presented.

The results show that the MOR and LOP present behavior with statistically significant differences ($p < 0.05$) between PVA and PVA + PET formulations in conditions without aging and after 200 cycles. Samples reinforced with PVA + PET fibres showed a reduction in the MOR average results of 12.1% in the initial age and 17.9% after 200 cycles compared to the samples with formulation containing only PVA fibres. For the mechanical properties of MOE and SE statistically significant differences between the two formulations were not identified in the condition without aging. After 200 cycles of accelerated aging test a reduction in the SE results for the composite with PVA + PET fibres were identified although toughness remained high for corrugate sheet applications.

Table 3 – Mechanical properties of flat samples extracted from the corrugated sheets before the aging test

Fibres	MOR (MPa)	LOP (MPa)	MOE (GPa)	SE (kJ/m^2)
PVA	13.81 ± 0.81 **a**	5.41 ± 0.78 **a**	8.78 ± 0.66 **a**	11.83 ± 1.38 **a**
PVA + PET	12.14 ± 0.99 **b**	4.39 ± 0.83 **b**	8.29 ± 1.60 **a**	11.12 ± 1.30 **a**

* Different letters in same column represent statistically significant difference ($p < 0.05$)

Table 4 - Mechanical properties of flat samples extracted from the corrugated sheets after the aging test

Fibres	MOR (MPa)	LOP (MPa)	MOE (GPa)	SE (kJ/m^2)
PVA	13.02 ± 0.60 **a**	5.08 ± 0.37 **a**	9.82 ± 0.47 **a**	8.72 ± 0.51 **a**
PVA + PET	10.69 ± 0.50 **b**	4.08 ± 0.73 **b**	10.59 ± 0.74 **a**	6.11 ± 0.60 **b**

* Different letters in same column represent statistically significant difference ($p < 0.05$)

Figure 1 shows the stress x strain typical curves for flat samples extracted from the corrugated sheets.

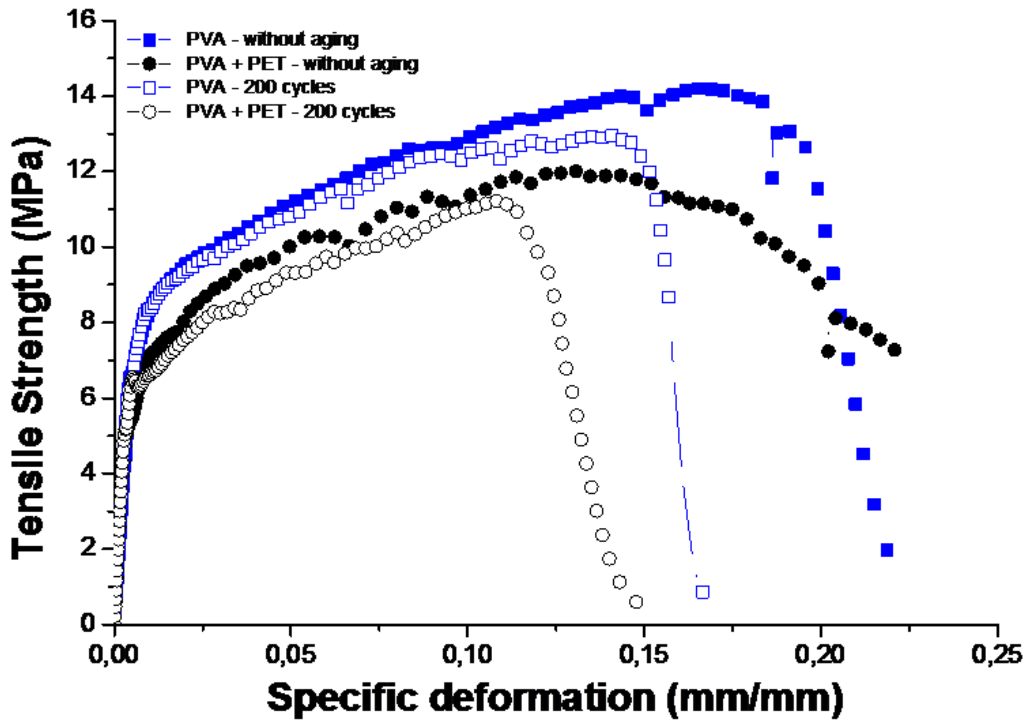

Figure 1 - Stress x strain typical curves for the flat samples extracted from the corrugated sheets.

Corrugated sheets

Tables 5 and 6 show average values and standard deviation of the physical properties (bulk density and water absorption) for the corrugated sheets with PVA fibres or PVA + PET fibres in the initial age and after 7 months of natural aging. An inferential statistical analysis comparing the experimental values by the Tukey test, with a 5% significance level is also presented.

The results indicate that there is a significant statistical difference ($p < 0.05$) for water absorption between PVA and PVA + PET formulations in conditions without aging and after natural aging for 7 months. The samples of the flat samples extracted from the corrugated sheets were taken from the middle of the tile and in the case of corrugated sheets side of the samples were cut (longitudinal). It is expected that there are density gradients in a cement tile and the difference between the results of flat samples and corrugated sheets show this gradient. It is also possible to observe an increase in the values of bulk density after aging what is also expectable due to continued hydration and/or natural carbonation of the corrugated sheets exposed to natural weathering.

Table 5 – Physical properties of the corrugated sheets with PVA or PVA+PET fibres before the aging test

Fibres	Bulk density ($g.cm^{-3}$)	Water Absorption (%w/w)
PVA	1.51 **a**	27.08 **a**
PVA + PET	1.52 **a**	25.50 **b**

* Different letters in same column represent statistically significant difference ($p < 0.05$)

Table 6 - Physical properties of the corrugated sheets with PVA or PVA+PET fibres after the aging test

Fibres	Bulk density ($g.cm^{-3}$)	Water absorption (%w/w)
PVA	1.62 ± 0.01 **a**	22.27 ± 0.30 **b**
PVA + PET	1.59 ± 0.05 **a**	23.98 ± 1.29 **a**

* Different letters in same column represent statistically significant difference ($p < 0.05$)

Tables 7 and 8 show average values and respective standard deviation for the failure load under flexural test for the corrugated sheets reinforced with PVA fibre or PVA + PET fibres. An inferential statistical analysis comparing the experimental values by the Tukey test, with a 5% significance level is presented.

The results revealed that there is a statistical difference between PVA and PVA + PET formulations without aging and after 7 months of natural aging. After the natural aging test, the corrugated sheets with PVA fibres presented an increase of 13% in the failure load and the corrugated sheets with PVA + PET fibres a reduction of 7%. The two formulations met the minimum load requirement of 2500 N/m as established by the Brazilian Standards NBR 15210-1 for corrugated sheets with thickness of 5 mm (class B).

Table 7 – Mean failure load of corrugated sheets with PVA or PVA+PET fibres – before aging test

Fibres	Failure load (N/m)
PVA	2530 ± 83 **b**
PVA + PET	2742 ± 33 **a**

* Different letters in same column represent statistically significant difference ($p < 0.05$)

Table 8 – Mean failure load of corrugated sheets with PVA or PVA+PET fibres – after natural aging test

Fibres	Failure load (N/m)
PVA	2893 ± 228 **a**
PVA + PET	2554 ± 47 **b**

* Different letters in same column represent statistically significant difference ($p < 0.05$)

Figure 2 shows the stress x strain typical curves for corrugated sheets with PVA or PVA+PET fibres after 7 months of natural aging test. The behavior confirms that the results for failure loads are reduced because of the partial substitution of PVA by PET fibre. However it is possible to see a tendency of increased deformation after cracking for those corrugated sheet with PET fibres in their formulation.

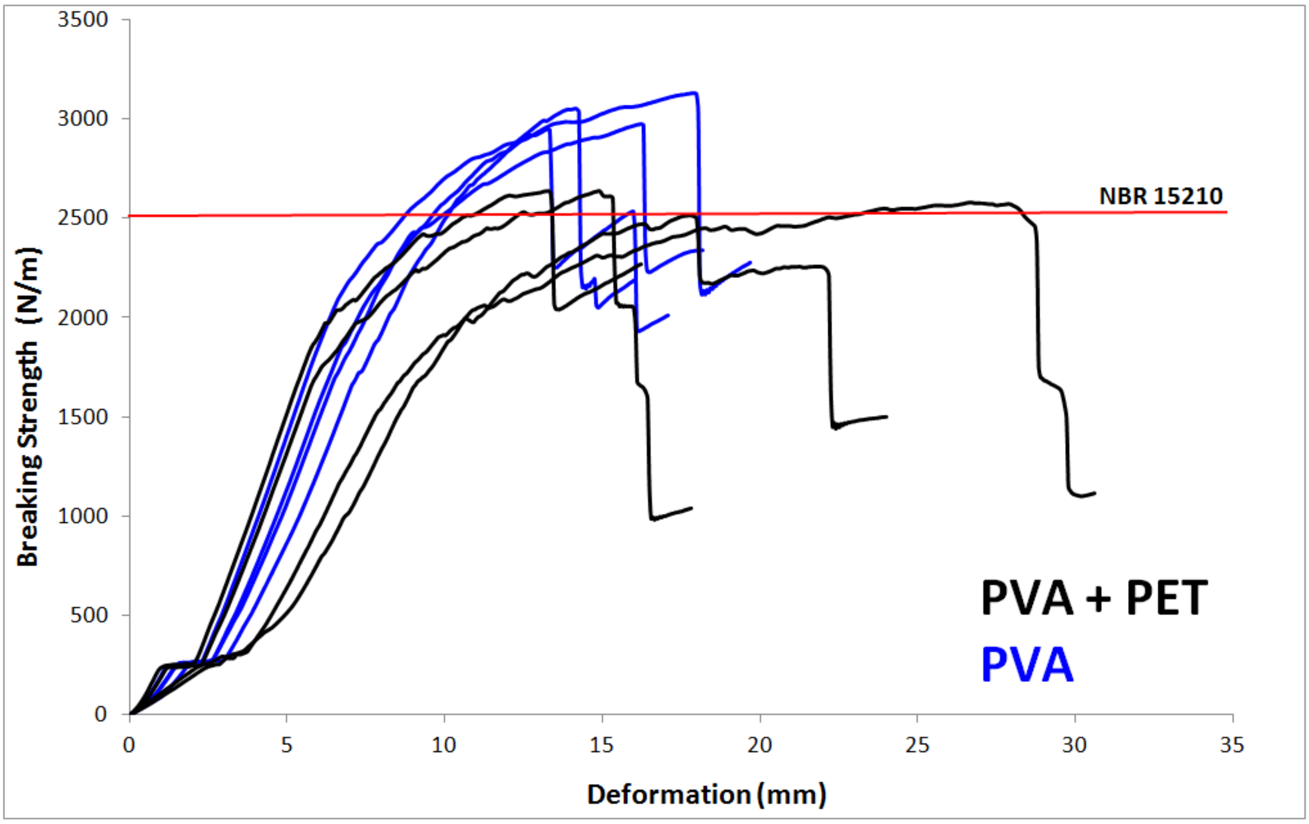

Figure 2 - Stress x strain typical curves for corrugated sheets after natural aging test.

CONCLUSION

The results indicated that samples with 15% of PET fibres are not statistically different in density, water absorption and porosity when compared with samples containing 100% PVA fibres before and after accelerated aging test.

In the initial age, the mechanical properties presented significant statistical difference with a 12% reduction in the modulus of rupture for the formulation with PVA + PET fibres compared to the formulation with only PVA fibre.

After accelerated aging, there was a 18% reduction in the modulus of rupture of samples with PET fibres.

The corrugated sheets with PVA and PET fibres followed the same tendency, however maintaining the load of rupture before and after natural weathering above the minimum recommended (2500 N/m) by the Brazilian Standards NBR 15210:2014.

The physical and mechanical characterizations suggest an acceptable performance of the fibre cement sheets with PVA and PET fibres for the conditions applied in this experimental study.

ACKNOWLEDGEMENTS

INFIBRA S/A – Brazil.

REFERENCES

AMERICAN SOCIETY FOR TESTING AND MATERIALS. ASTM C 948-81: test method for dry and wet bulk density, water absorption, and apparent porosity of thin sections of glass-fiber reinforced concrete. West Conshohocken, PA, USA, 1981.

ASSOCIAÇÃO BRASILEIRA D ENORMAS TÉCNICAS. NBR 15210-1: Telha ondulada de fibrocimento sem amianto e seus acessórios. Parte 1: Classificação e requisitos. Rio de Janeiro, Brasil, 2014.

ASSOCIAÇÃO BRASILEIRA D ENORMAS TÉCNICAS. NBR 15210-2: Telha ondulada de fibrocimento sem amianto e seus acessórios. Parte 2: Ensaios. Rio de Janeiro, Brasil, 2016.

Cassidy, P. E., Mores, M. 1992. "Geotexcorrugated sheets and Geomembranes" 11, 61.

Jeona, H.Y., Chob,S. H., Mokc, M. S., Parkd, Y. M., Jange, J. W. 2005. "Assessment of chemical resistance of textile geogrids manufactured with PET high-performance yarn". Polymer Testing 24, 339–345.

Koerner, R. M., Lord Jr, A. E., Hsuan, Y. H. 1992. "Geotexcorrugated sheets and Geomembranes" 11, 151.

Lepech, M. D., Li, V. C., Robertson, R. E., & Keoleian, G. A. (2008). "Design of green engineered cementitious composites for improved sustainability". ACI Materials Journal, 105(6), 567–575.

Li, V. C., Wang, S., & Wu, C. (2001). "Tensile strain-hardening behavior of polyvinyl alcohol engineered cementitious composite (PVA-ECC)". ACI Materials Journal, 482–492.

Li, V. C., Wu, C., Wang, S., Ogawa, A., & Saito, T. (2002). "Interface tailoring for strain-hardening polyvinyl alcohol-engineered cementitious composite (PVA-ECC)". ACI Materials Journal-American Concrete Institute, 99(5), 463–472.

Reunion internationale des laboratoires d´essais et des recheches sur les materiaux et les constructions (RILEM). rilem 49tfr: testing methods for fibre reinforced cement-based composites. Matériaux et Constructions, Paris, v. 17, n. 102, p. 441-456. 1984.

Silva et al. (2005). "Degradation of recycled PET fibers in Portland cement-based materials". Cement and Concrete Research, 35(9), 1741–1746.