HARDWOOD PULP FIBRE AS ALTERNATIVE TO ENGINEERED CEMENT BASED COMPOSITES

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ABSTRACT

The objective of the current research is to evaluate the advantages of using hardwood short fibre pulp (Eucalyptus) as alternative to the softwood long fibre pulp (Pinus) and polymer fibres, traditionally used in reinforcement of cement based materials. The effect of the vegetable fibre length in the microstructure and in the mechanical performance of fibre-cement composites were evaluated before and after accelerated ageing cycles. Hardwood pulp fibres present improved dispersion in the cement matrix and provide higher number of fibres per unitary weight or volume, in relation to softwood long fibre pulp. The short reinforcing elements lead to an effective crack bridging of the fragile matrix, which contributes to the improvement of the mechanical performance of the composite after ageing. All the promising results signalise to the potential of the hardwood short fibre pulp (Eucalyptus) to partial replacement of the polymer fibres in air curing process.

KEYWORDS

Drainage; Durability; Eucalyptus pulp; Fibre-cement; Short fibres.

INTRODUCTION AND STATE OF ART

Mechanical properties of fibre-cement composites are very sensitive to the uniformity of volume distribution (dispersion) of the fibres. According to Bentur and Mindess (2007), a geometrical parameter which is of significance in controlling the performance of the composites is the distance (spacing) between the fibres. Usually, cracks initiate and advance from the section of a composite that has larger fibre-free matrix regions and fibre clumping (Akkaya et al., 2000). The initiation of a crack requires less energy if it increases the size and number of matrix regions that are not reinforced by fibres. This phenomenon is more pronounced if it is considered the progressive brittlement of the cement matrix throughout its ageing.

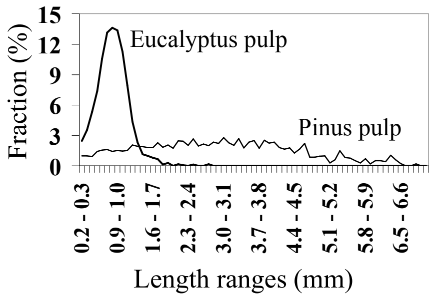

Fig.1: Fibre length distribution of Eucalyptus and Pinus pulps, measured with Pulptec™ MFA-5000 fibre analyzer.

Research into the effect of several vegetable fibre properties on mechanical performance of fibre-cement composites (Campbell and Coutts, 1980) showed the advantages of composites with desirable strength properties produced from long-fibered wood species – i.e., softwood pulps. Thus, in most cases, softwood fibre (mainly *Pinus sp*) has replaced asbestos fibre as reinforcement in commercial cement products. However, how to decrease the number of matrix regions that are not reinforced by fibres has been insufficiently explored. The number of reinforcing elements is a key aspect in the fibre-cement engineering.

Pinus pulp has a reasonably high market price. Thus, considerable research effort has gone into the study of fast growing and cheaper alternatives to the fibre supply. In tropical regions, Eucalyptus is a fast growing hardwood specie with good fibre qualities and relatively cheap market price. Although Eucalyptus pulp has been widely employed in the paper industry throughout the world, there is limited information in the scientific literature concerning its use as reinforcement in fibre-cement. Eucalyptus pulp presents shorter fibres (0.83 ± 0.01 mm) than Pinus pulp (2.40 ± 0.09 mm) and is likely to be less heterogeneous in length (Fig.1). Using short fibres is possible to have a higher number of fibres per volume or weight in relation to long fibres, and therefore to reduce the fibre-free areas, i.e. the distance between the fibres. Additionally, the smaller the fibre length (which generally relates to a lower aspect ratio), the easier the fibre dispersion (Chung, 2005).

Therefore, the objective of the present research was to evaluate the suitability and advantages of hardwood short fibre pulp (Eucalyptus) as alternative to the softwood long fibre pulp (Pinus) widely used in the manufacture of fibre-cement building products. The current research also investigates the potential of partial replacement of more expensive polymer fibres by the hardwood short fibre pulp.

PROBLEM ADDRESSED

Mainly in the developing countries, there is the need for low cost fibre-cement with acceptable performance under aggressive climates. The available technologies for fibre-cement production in the developed world require high investment, sometimes impracticable if considered the reality of the low income countries. It is a concern for the fibre-cement industries the availability of the conventional raw-materials commonly used in the manufacture of the asbestos-free fibre-cement. Therefore, there is the demand for alternative raw-materials, as appropriate fibres and binders, to substitute traditional ones, which involve high cost and great consumption of energy in their processing. Another concern is the durability of the products. The raw materials need to be appropriate to the asbestos-free technologies in emergent markets, without losses in the performance of the composites. Finally, to advance in the use of vegetable fibres in cement based composites it is essential to further study the fibre properties, which provide optimum performance in the fibre-cement manufacture.

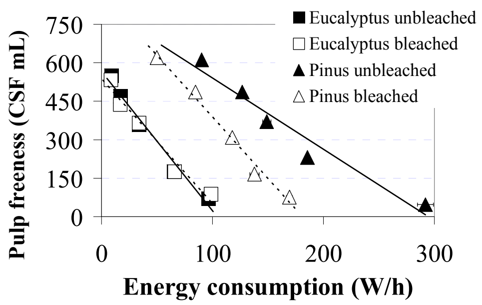

Fig.2: Energy consumption in a PFI refiner in relation to the pulp freeness.

KEY INNOVATIONS

Eucalyptus pulp (short fibres) and hardwood pulp in general is getting market through the world, which justifies the expectation in its adaptability to reinforcement of cement based materials. Indeed, there is still a lack of information regarding the influence of the vegetal fibre length in the mechanical performance of the composites. Despite some trials of using Eucalyptus pulp in fibre-cement manufacture at industrial scale, no information was published about the advantages in its use and about the durability of the product. The present work shows the progress in the engineering of composites by the use of hardwood short fibre pulp in order to improve the distribution of the reinforcement into the composite. A deep investigation at microstructural level was done to explain some complex interactions between the fibre properties and the final product.

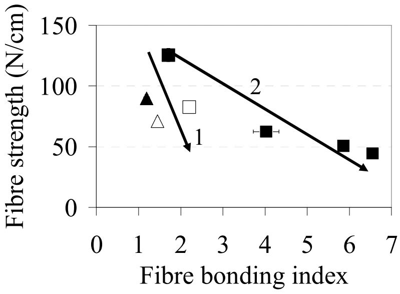

Fig.3: Fibre strength in relation to the fibre bonding index (squares are Eucalyptus and triangles are Pinus). Arrows 1 and 2 represent the effect of bleaching and refining respectively.

Pinus fibres are usually highly refined in order to fibrillate their surface and improve fibre to cement bonding, processing and strength of the fibre-cement composites produced by the Hatsheck process (Coutts, 2005). However, there was no evidence that refining improves the performance of products reinforced with Eucalyptus pulp. Avoiding or decreasing the intensity of fibre refining could be a great advantage during the stock preparation due to savings in refining energy (Fig.2) as well as to the minimization of damages caused in the fibre cell wall, which in general decrease their strength (Fig.3). Therefore, short vegetal fibres may improve the processing of the fibre-cement product with minimal expenses in their preparation. Additionally, there is the possibility of a more sustainable and competitive fibre-cement production when using a cheaper fibre alternative that provides economy in its manufacture and improvements in the durability. The present research also contributes with more complete information about Eucalyptus and Pinus fibres to advance in their utility and to the technological progress of fibre-cement production.

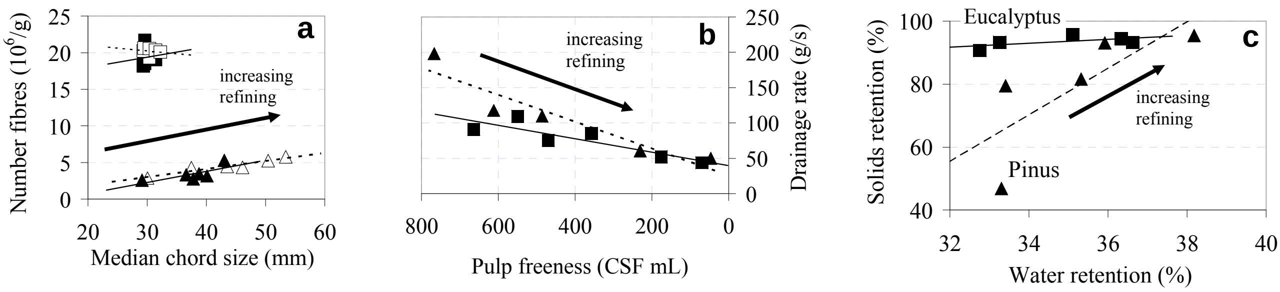

Fig.4: (a) Number of fibres per gram in relation to the median chord size in the suspensions in function of the pulp freeness; (b) drainage rate of the fibre-cement suspensions in relation to the pulp freeness; (c) solids retention in relation to the water retention in the cake. Legend: ■ and □ represent Eucalyptus unbleached and bleached pulps respectively; ▲ and △ represent unbleached and bleached Pinus pulps respectively.

APPLICATIONS / IMPLEMENTATIONS / RESULTS

Eucalyptus and Pinus kraft pulps were refined in a PFI lab refiner to promote the surface fibrillation of the fibres, as usually done in the fibre-cement industry. Fig.3 depicts the zero-span resistance of the pulp fibres in different conditions. Unbleached Eucalyptus pulp presented more resistant fibres than Pinus pulp, while bleaching and refining diminish the resistance of the fibres.

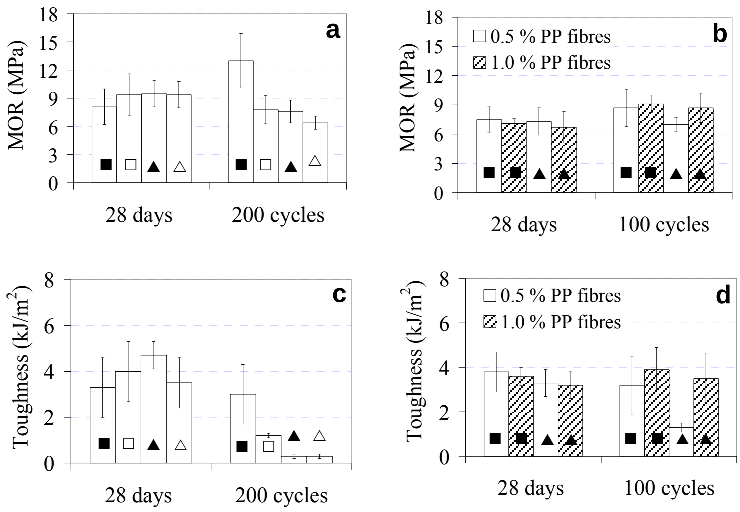

Fig.5: Average values and standard deviation of modulus of rupture (MOR) and toughness of the fibre-cement composites reinforced with cellulose pulp combined or not with polypropylene (PP) fibre. Legend: ■ and □ represent Eucalyptus unbleached and bleached pulps respectively; ▲ and △ represent unbleached and bleached Pinus pulps respectively.

The size of the chords in the fibre-cement suspensions and their drainage and retention properties were monitored as described in Negro et al (2006), in order to evaluate the effect of using short fibre pulp in fibre-cement manufacturing processes. Eucalyptus pulp presents a number of fibres per gram four times higher than Pinus pulp (Fig.4a). The more efficient dispersion of the Eucalyptus fibres in the cementitious suspension can be observed in the Fig.4a by the lower size of chords in relation to the suspensions with Pinus pulp. The higher chords in the suspensions with Pinus are due to the fibre clumps or flocs visually observed. In the composite, these fibre clumps will cause local fibre concentrations and local fibre-free areas, which results in poorer crack bridging.

The higher number of fibres did not prejudice the drainage rate of the fibre-cement suspensions (Fig.4b), despite it improved significantly the solids retention during the dewatering of the suspension (Fig.4c). As it was expected, it is possible to improve the solids retention of the Pinus pulp decreasing its pulp freeness, i.e. increasing the refining (Fig.4c). Fig.2 depicts the higher energy consumption of refining Pinus pulp in relation to Eucalyptus pulp for the same level of pulp freeness (intensity of refining).

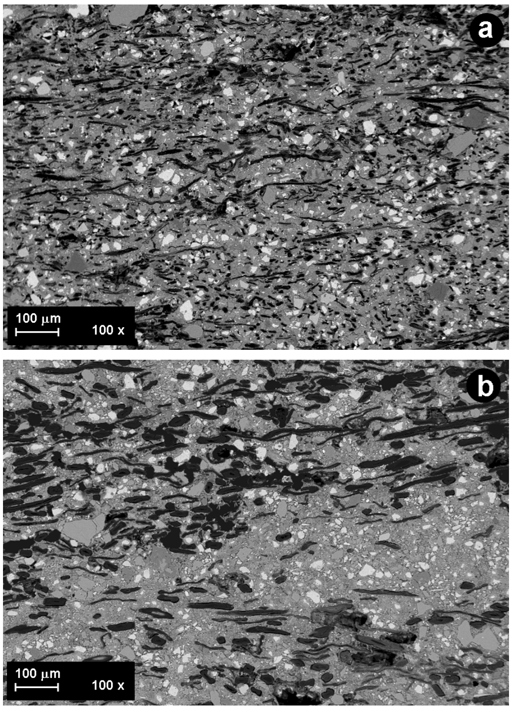

Fig.6: SEM BSE image of composites reinforced with Eucalyptus pulp (a) and Pine pulp (b).

Composites were prepared in laboratory using the vacuum dewatering and pressing technique (crude simulation of the Hatsheck process) (Savastano et al., 2000). After 28 days of cure, composites reinforced with 10% (by mass) of Eucalyptus or Pinus pulp presented similar mechanical performance (Fig.5). After 200 accelerated ageing cycles (EN 494, 1994) the composites with Eucalyptus pulp presented an improved mechanical performance in relation to the composites with Pinus pulp. The short Eucalyptus fibres are better distributed (Fig.6) and the bridging fibres share the load and transfer it to the other parts of the composite, increasing the MOR and toughness of the composite. No significant differences were found in the mechanical performance of composites reinforced with Eucalyptus fibres + 0.5% (by mass) of polypropylene (PP) fibres in relation to 1.0% of PP fibres, after 100 ageing cycles (Fig.5b and 5d). In the case of composites with refined Pinus pulp, the use of 0.5% of PP fibres instead of 1% of PP fibres led to the significant decrease of their toughness after accelerated ageing.

The calculated fibre spacing (Bentur and Mindess, 2007) is at least two times higher for the Pinus fibres in relation to the Eucalyptus fibres. Furthermore, due to the long fibres in the Pinus pulp, there is the tendency to cling to one another and prejudice the reinforcement.

In the analysis with Atomic Force Microscopy (AFM), the surface of Eucalyptus fibres presented some fibrillar structure in the majority of the samples (Fig.7a). In the Pinus fibres the typical surface structure was granular (Fig.7b), possibly related to amorphous non-carbohydrates (i.e. lignin and extractives) in the fibre surface. The fibrillar surface structures of the Eucalyptus fibres provide a higher rough mean square (RMS = 74 ± 18 nm) than Pinus fibres (RMS = 52 ± 10 nm) which is an indicative of the higher potential of the Eucalyptus fibres to anchorage in the cement matrix. Arrows in the Fig.8a shows the improved interface of the Eucalyptus fibres in relation to Pinus fibres (Fig.8b), in the cross sections of composites after accelerated ageing cycles. Fig.8c presents the larger pores (in the interval from 1 to 10 µm) found by mercury intrusion porosimetry (MIP) in the composites reinforced with Pinus, which is attributed to the voids in the fibre-matrix interface (arrows in the Fig.8b).

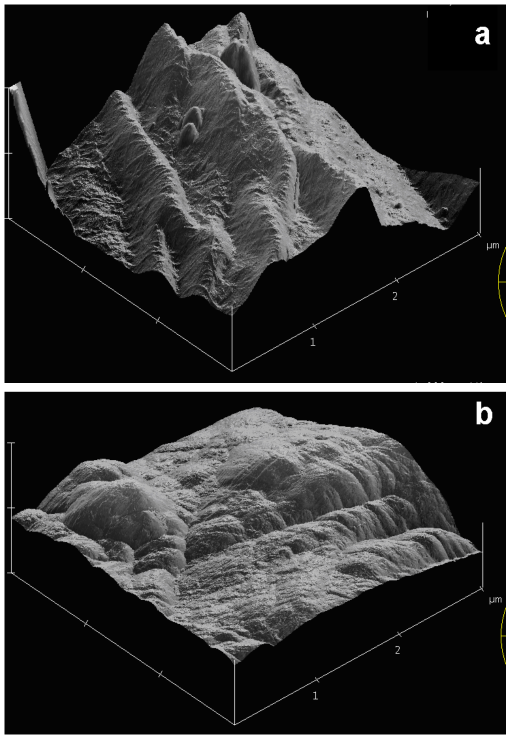

Fig.7: AFM topography images of unbleached Eucalyptus fibres (a) and unbleached Pinus fibres (b). Image sizes are 3 µm X 3 µm.

As a final observation, the use of short fibre pulp did not increase the shrinkage of the composites in different relative humidity conditions (Fig.9) no matter the greater amount of reinforcing elements. Autoclaving is presented as an alternative to reduce the dimensional instability of the composites.

CONCLUSION

The use of hardwood short fibre pulp (Eucalyptus) can save energy in the pulp preparation (refining) during the processing of fibre-cement products. The higher number of reinforcing elements in the Eucalyptus pulp provides an effective crack bridging, contributing to the maintenance of the mechanical performance of the composite after accelerated ageing cycles. The SEM observations suggest that in short fibre composites the distribution of fibres is more uniform. The clumping present in the Pinus fibre-cement specimens appears to reduce the effectiveness of the fibres at stopping cracks due to bending, whereas the initiation of those cracks is made more likely by the greater extension of unreinforced area found in specimens with softwood long fibre pulp (Pinus). The AFM images also provide more detailed information about the fibre surface morphologies. It is reasonable to suppose that rougher surface in the Eucalyptus fibres increase bonding between fibres and matrix. The current results allied to further studies in the near future, encourage the partial replacement of the more expensive polymer (e.g. PP or PVA) fibres by the short vegetable pulp fibres (Eucalyptus pulp) in the fibre-cement production.

DISSEMINATION PLAN

The technology for using the Eucalyptus pulp has been already applied in the industry as mill trials, but its viability is still under study and companies will benefit of knowing all available information. Therefore, the dissemination plan of this work consists of turning available the raw materials to the industries, including their adaptation to the conventional methods of production (e.g. Hatshek process). The dissemination of the use of Eucalyptus pulp fits well with the growing necessity of more sustainable raw-materials and permits the partial substitution of the more expensive polymer fibres used to the maintenance of the composites durability under aggressive climates. Furthermore, is plan to publish two detailed scientific papers. A presentation will be available during the IIBCC conference for all interested parties.

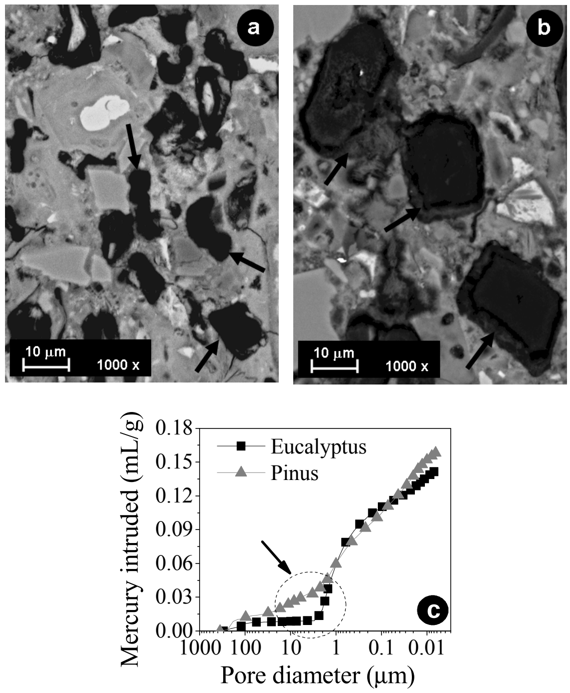

Fig.8: SEM BSE image of composites reinforced with Eucalyptus (a) and Pine pulps (b) after accelerated ageing. Cumulative mercury intrusion porosimetry (MIP) of the respective composites (c).

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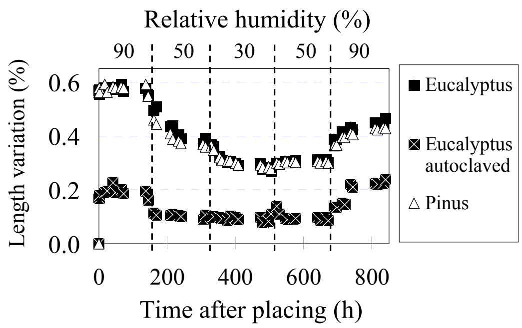

Fig.9: Dimensional variation of the composites in relation to the relative humidity.

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