USE OF WASTES AS A SOURCE OF MINERALS AND CELLULOSE IN FIBRE REINFORCED CEMENT

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ABSTRACT

The effect of replacement part of cellulose fibres and minerals by different from industry and agriculture wastes in fibre reinforced cement production was studied. Three different wastes were tried: deinked sludge, maize straw and hemp waste fibres. Pulps were obtained from maize straw and hemp fibres by organosolv cooking with different conditions before their use as a source of fibres.

Results showed that the replacement of a 5% of virgin fibres by the cellulose from deinking sludge could improve product strength. Furthermore, pulps from maize straw and hemp could be used as a source of cellulose without detrimental effects on retention and hydration processes. These results, if confirmed on mill scale, would improve the economy of the process due to lower cost of wastes compared with the pine Kraft pulp and, at the same time, they could open a new way to use these wastes instead of dumping or burning..

KEYWORDS:

waste management; flocculation; retention; drainage.

INTRODUCTION

Fibre reinforced cement have been traditionally manufactured with asbestos fibres due to their low cost and natural compatibility with cement matrix which assured a simple and cheap production and high product quality and durability. Since asbestos were forbidden many other fibres have been tried with the aim of producing a fibre reinforced cement with similar properties to the asbestos reinforced cement or even better, with as low as possible investment. Polypropylene, polyacrylic, polyvynilalcohol (PVA), glass, carbon and cellulose fibres are only some of the fibres tried to replace asbestos. Cellulose and PVA fibres are the most used ones in the global fibre-cement production, especially for roofing, due to its low cost, high availability and its compatibility with the existing process technology (Hannant, 1995, Kakemi and Hannant, 1996; Coutts, 2005).

The most usual source of cellulose fibres for fibre-cement is unbleached Kraft pulp from pine (Mohr et al., 2004), although thermo mechanical pulp (TMP) have been also tried (Blankenhorn et al., 2001; Bezerra et al., 2006; Mohr et al., 2006). During the last years, recycled fibres have been also considered as an alternative for fibre-cement industry because of their low cost, but many of them have detrimental effects on the product properties (Soroushian, 1995; Savastano et al., 2000; Agopyan et al., 2005; Bezerra et al., 2006; Mohr et al., 2006). Furthermore, the effect of the origin of cellulose fibres on the properties of fibre-cement has been also studied: softwood pulps, hardwood pulps, sisal fibres, coir fibres, banana waste fibres, rice husk and bamboo pulp are only some of the different fibres tried (Cook et al., 1978; Savastano et al., 2000; 2005; 2006; Souza et al., 2006).

Nowadays the social and economical framework demand high quality products manufactured by low cost and environmental friendly processes. The use of wastes as a source of fibres or minerals in fibre reinforced cement can be a way to satisfy this demand. This research is aimed in studying the feasibility of using three kinds of wastes for fibre reinforced cement manufacture: deinking sludge from recycling paper production, hemp waste fibres and maize waste fibres.

Deinking process generate a substantial quantity of wastes. The amount of sludge on a dry weight basis may vary from 20% in a newsprint mill to 40% in a tissue mill (Krigstin and Sain, 2006). In general, the management of this waste is an extra cost for the papermakers, therefore, it could be a free raw material for fibre reinforced cement production. The composition of this waste is cellulose short fibres, silica, calcium carbonate and clays and other organic and inorganic materials, but it varies with the characteristics of recovered and recycled paper and with the mill yield and with the time and there is a generalised trend towards reducing the cellulose loses in the mill (Latva-Somppi et al., 1994). Therefore, this waste could be a source not only of fibres but also of mineral in the fibre-cement production.

The maize production generates a large amount of waste biomass. Part of that waste is used as food for cows, but it is difficult to digest and its nutritive value is poor, this limits its use. Furthermore, the use of cereals to produce bio-diesel has increased the production of this waste and other applications for these waste cellulose fibres must be developed. Therefore, this waste could be also a very cheap source of cellulose fibres for fibre-cement manufacture.

The production of hemp fibres, which are very strong fibres used in textile industry and as reinforcement fibres in composites, generates a large amount of biomass. The fruits are used as food for animals or as a raw material in oils and cosmetics production, foils are used as a fuel or composted, but the part of the tail that is separated from the hemp fibres is a waste more difficult to manage.

Maize and hemp wastes can be pulped by environmental friendly digestion processes to produce a cellulose pulp. The aim of this research is to study if these pulps can replace the pine Kraft pulp used in the fibre-cement manufacture without affecting the process and the hardening of the product.

MATERIALS

Fibre-cement specimens are prepared with the compositions summarised in table 1. The fibre-cement mixture containing PVA fibres (FC1) was prepared with waste pulps because its lower amount of cellulose, which minimise the effect of uncooked material and lignin on the cement hardening. The mixture FC2 was selected to replace fibres by the cellulose contained in deinking sludge because its high content in cellulose fibres and silica.

Table 1 Characteristics of the waste pulps after cooking

Raw materials	Cellulose	ASTM II Cement	Microsilica	PVA	Silica	Al_2O_3	Clay
FC1 (%)	3,2	91	4	1,8	0	0	0
FC2 (%)	9	47	0	0	36.2	3.8	3.4

The pulps used were: Pinus Radiata unbleached Kraft fibres, refined at 450 ºCSF, hemp waste pulp and maize waste pulp, both obtained by an organosolv cooking with ethanolamine. Some properties of the cooked waste pulps are summarised in table 2. Maize 2 and waste hemp 2 were cooked for a longer time and at higher temperature than maize 1 and waste hemp 1.

Table 2. Characteristics of the waste pulps after cooking

	Kappa	Uncooked materials (%)	Millions of fibres/g	Fibre length (mm)
Maize 1	15,2	5.2	33.5	0.81
Maize 2	4,8	3.3	86.4	0.46
Waste hemp 1	33.2	12.4	50.0	0.54
Waste hemp 2	25.6	6.9	101.6	0.47
Kraft Pine			2.34	1.86

Deinking sludge from a local recycled newspaper mill was used to provide part of the cellulose and part of the minerals of the composite. Diferent replacements of fibres by the cellulose contained in the sludge were tried. The composition of the deinking sludge is summarised in table 3.

Table 3. Deinking sludge composition (% on dry weight).

Minerals (%)				**Organic materials (%)**	
Carbonates	Clay	Talc	Others	Cellulose fines/fibres	Others
44.1	13.86	3.15	1.89	35.15	1.85

In the case of using deinking sludge, the content in standard silica of the FC2 specimens was reduced in the same amount that the contribution of the inorganic compounds of the sludge to the inorganic matrix.

100 ppm of an anionic polyacrylamide (APAM) was used as retention aid to prepare the probes.

METHODS

Replacing raw materials by deinking sludge.

For each trial 7 specimens of fibre-cement were prepared to test their properties. The specimen manufacturing procedure simulated the fibre-cement Hatschek process at mill scale. 1 L of 10% fibre-cement suspension was prepared using the raw materials indicated above, except the flocculant, after mixing, it was stirred for 45 s to homogenize it before adding 100 ppm of APAM. 30s after the flocculant addition, the mixture was poured into a vacual casting box of 210 X 80 mm with a sieve, used as a filter medium. Drainage took place with a vacuum of 250 kPa. Finally, an 11 kg weight was put on the cake for 5 s to simulate the pressure from the cylinder former in process and the specimen was removed from the sieve and pressed for 5 s at 6.2 MPa. The specimens were stored between two steel plates inside a sealed plastic bag until stacks of seven were prepared. The FC2 specimens were stored during 24 h in a curing chamber with a water-saturated atmosphere, before curing in an autoclave at 9 atm and 180ºC for 9 h. Finally, the specimens were stored in water saturated in $Ca(OH)_2$ until the flexural test, which was made 7 days after starting the specimen preparation.

Cellulose virgin fibres were partially substituted by the cellulose of the sludge and the silica was substituted by the inorganic material of the sludge. Different substitution grades of virgin cellulose by fibres of sludge were tried.

Several measurements were carried out on the manufactured specimens after seven days curing: the density of the specimens, the Breaking load in central point bending and the thickness following the standard EN 494 and the water absorption, which is strongly dependent on the amount and kind of fibres. This last measurement consist on introducing the specimen in water during 24 h and weight it after eliminating the excess of water from the surface and after drying it at 105ºC for 48 h.

Replacing pine pulp by waste fibres.

Effect of waste fibres on retention of solids in the fibre-cement was evaluated by using a vacuum drainage tester (VDT) device which allows determine drainage time and retention of solids. It has two jars separated by a barrier: the upper jar is used to keep the fibre–cement suspensions stirred until the drainage starts. In a typical trial, a 400 ml of fibre-cement suspension-sample, prepared with water saturated with $Ca(OH)_2$, was stirred at 600 rpm during 6 min to disperse the materials. Then stirring intensity was decreased to 300 rpm. After 5 min, the stirring was stoped, the barrier was removed and the suspension was drained to the second jar in which an 18 mesh wire was located. The suspension was drained under a certain vacuum (0,2 atm) through the filter and a computerized balance records the mass of drained water over time (Negro et al., 2006b). Retention and cake humidity were determined from the analysis of the formed cake. No flocculant was used in these trials. In this way the interaction of fibres with solids has a higher relevance in retention and effects of fibres morphology, cooking and origin on retention and cement hardening are enhanced.

The effect of the waste fibres on cement hardening was evaluated by using the Vicat device adapted to fibre-cement suspensions. Mixtures were prepared with a consistency of 50 g/l stirring at 600 rpm to asure the right dispersion of fibres in the matrix. Then, the excess of water was removed up to obtain a mixture with a ratio solids/water of 1/1. The penetration of the Vicat needle was measured 48 h after the sample preparation, because of the slow hardening of this kind of mixtures.

RESULTS

Replacing raw materials by deinking sludge.

Figure 1 shows no observation of a significant effect of the sludge content on the humidity of the fibre-cement specimens after pressing. Taking into account that the percentage of cellulose remains constant this means that the swelling ability of cellulose coming from sludge is similar to the swelling ability of virgin fibres used at the experimental conditions. Virgin fibre was unbleached softwood and fines from sludge have suffered several cycles that have decreased their swelling ability. Therefore, both kind of cellulose has a low swelling ability.

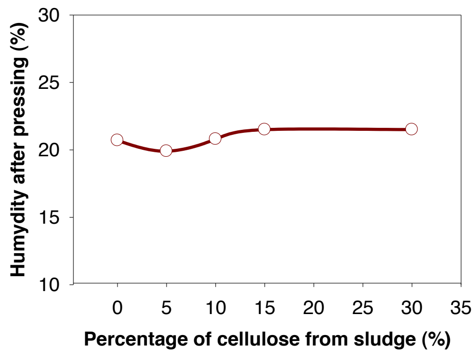

Figure 1. Effect of deinking sludge on water retention

Figure 2 shows that maximum strength can be achieved replacing a 5% of cellulose with deinking sludge. This strength is expressed as a strength module, to eliminate the effect of the thickness on the results. The strength module was calculated from the breaking load and the specimen dimensions by using the equation (1):

$$MR = \frac{300BL}{Th^2} \quad (1)$$

where: *MR* is the strength module (MPa), *BL* is the breaking load (kg) and *Th* is the thickness (mm).

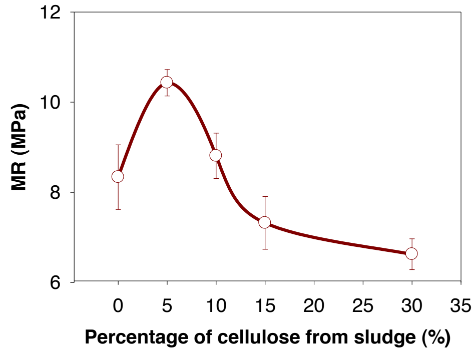

Figure 2. Effect of sludge on the strength module of the manufactured specimens.

The effect of using deinking sludge on the strength is not related with the density of the product, because it increased only slightly when up to the 10% of virgin cellulose were replaced by the cellulose of the sludge (Figure 3).

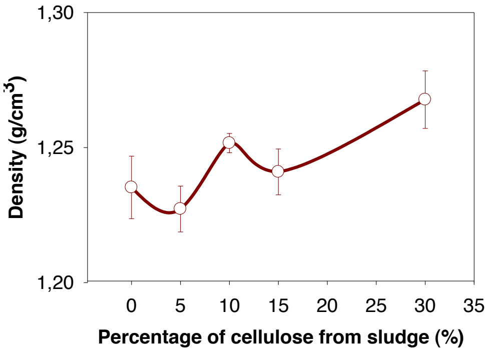

Figure 3. Effect of sludge on the density of the fibre-cement after curing.

The explanation for the increase in strength must be based in the interaction between the fibres and the matrix. The fibres and fines coming from the sludge have a higher specific surface area than the virgin fibres, because they are shorter, a large number and many of them are thinner. Therefore the interaction between the fibres and fines from the sludge and the minerals could be higher, than it is with virgin cellulose.

Furthermore, the content of wood extractives in deinking sludge is much lower than in the virgin pulp. Figure1 has shown that those waste fines and fibres do not affect the water retention as they are cellulose like the virgin ones. Consequently the replacement of 5% of the virgin fibres by the cellulose from the sludge increases the interaction between fibres and minerals without the negative effect on the water retention. This explains the effect on the fibre-cement strength of low substitution grades.

However, the tensile strength of the fibres fines from sludge is lower than the tensile strength of virgin fibres. This has a negative effect on the fibre-cement strength and that is noticeable when the percentage of these fibres and fines on the cellulosic part of fibre-cement is more than 5%.

Water absorption of the specimens decreased slightly when up to 10% of virgin cellulose was replaced by the cellulose of the sludge. This could indicate that the use of a limited amount of deinking sludge on fibre-cement manufacture does not affect or even improve its behaviour in humid environments and its durability. However, to confirm the later an accelerated aging process with several soak-dry cycles should be carried out.

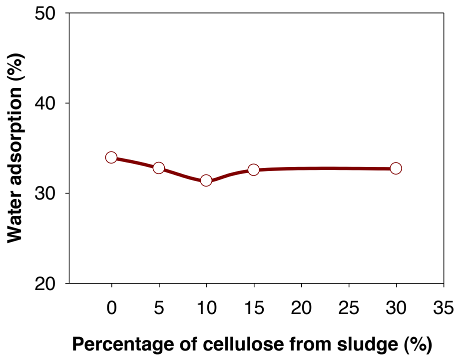

Figure 4. Effect of sludge on the water absorption of the fibre-cement probes.

Replacing pine pulp by waste fibres.

Table 4 shows the retention of solids and the Vicat needle penetration obtained with the different pulps were used as source of fibres. Results show that the replacement of pine pulp by softly cooked waste pulp decreased retention of solids, but if the waste pulp is enough cooked retention can even be increased. The reason is the high content on cellulose fibres of the well cooked pulp, which allows a higher interaction with the solids and a better formation of a kind of network.

The use of waste pulps did not increase the retention of water in the cakes. It even decreased slightly the humidity of the cakes, especially in the case of maize pulp. Results show that in the case of the waste pulps tested, the humidity of the cake increased with the Kappa number of the pulp used, which was not expected due to the barrier of lignin in the interaction between cellulose and water. The increase in the humidity can cause a decrease in breaking load, because when the water is consumed in cement hardening the water is replaced by voids, increasing the porosity of the composite. An optimal humidity is required which allows the bonding among fibre-cement layers in the formation of the sheets, but without an increase in the porosity.

Table 4. Effect of using waste fibres on fibre-cement retention and hardening.

	Pine	Maize 1	Maize 2	Waste hemp 1	Waste hemp 2
Solids retention (%)	60	54.6	65.0	49.3	68.8
Humidity (%)	56	50.7	47.2	57.1	53.2
Vicat needle penetration (mm)	1.5	2.5	1.5	1.5	2

The results obtained from the Vicat device show that only the poor cooked waste maize pulp (maize 1) has a significant effect on the cement hardening.

CONCLUSIONS

The use of deinking sludge as a source of fibres and minerals in fibre-cement manufacture could be feasible. It could contribute to reduce the production cost in raw materials in reducing the consumption of pine pulp and silica. Furthermore, it could even improve the fibre-cement strength if 5% of the virgin cellulose is replaced by cellulose from the sludge, and with a possibility to replace up to the 10% without reduction in the product strength.

The use of organosolv pulps obtained from cooking waste fibres from maize culture or hemp culture as source of fibres instead of pine pulp requires the optimisation of the cooking process. Pulps poor cooked decreased retention of solids and could increase the humidity of the fibre-cement, uncooked compounds and lignin contained in the poor cooked maize pulp can even affect the hardening of the cement. However, the cost of these pulps increase with the severity of the cooking process conditions.

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