

ALTERNATIVE USE OF DEINKING SLUDGE AS A SOURCE OF FIBERS IN FIBER-CEMENT MANUFACTURE

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The present paper, contributing to solving two different problems related both to the chemical industry and the environment, is a feasibility study on the utilization of the deinking sludge (the most important waste from papermaking) as a raw material for fiber-cement manufacture, in which asbestos has been recently replaced by other fibers because of the hazard it induces. The results obtained show that the use of deinking sludge as a source of cellulose in fiber-cement manufacture is feasible and could improve product strength, if 5% of the virgin fibers are replaced by fibers and fines from the deinking sludge. It is also possible to replace up to 10% of the virgin fibers, with no loss in product strength. These results, if confirmed on a mill scale, would improve the economy of the process, as due to lower waste costs.

Keywords: fiber-cement, deinking sludge, recycling, waste management, sustainability, papermaking wastes

INTRODUCTION

As known, papermaking is an industry leader from the standpoint of recycling and sustainability, the main reason being that virgin and recycled fibers can be used together, sometimes contributing with complementary characteristics. Recycling plays an important role in the sustainable development of the sector. The growth of the paper recycling industry during recent decades has produced an important environmental benefit, leading to the extension of the fiber life cycle, forest conservation and reduction of landfill requirements.

Nowadays, the world consumption of recovered paper is estimated as more than 165 million tons, which accounts for more than 40% of the raw material used in papermaking; it is estimated¹ that, by 2010, about half of the fibers used in papermaking worldwide will be recycled fibers. In 2005, Europe reached a recycling rate of 56%, meaning 47.5 million tons of recovered paper used as raw material in the European paper industry.

However, recycling operations, especially deinking, generate an important quantity of wastes, representing 70% of the wastes produced by the European pulp and paper industry. The amount of sludge on a dry mass basis may vary^{2,3} from 20% in a newsprint mill to 40% in a tissue mill.

Traditional practices of sludge disposal, including land spreading, landfilling and incineration, are no longer recommended, as due to their ecological and economic implications.^{1,4,5}

On the one hand, landfilling of biodegradable wastes is now limited by the European legislation; consequently, such waste is not efficiently incinerated because it contains large amounts of minerals, which increase the ash residues.³ On the other hand, the concentration of contaminants in the sludge, such as heavy metals and polychlorinated biphenyls, is low enough to take advantage of this waste.⁶ Therefore, new sludge management approaches, utilising this material in a value-added manner, should be sought.^{2,4,5}

For example, the use of deinking sludge on the soil has increased over the years, some of it being now mixed with secondary sludge, while some is composted after mixing with either absorbents or bulking agents with nitrogen sources, which improves the quality of the depleted soil by landspreading.⁷⁻¹⁰ Several authors have studied the possibility of re-introducing the minerals contained in the sludge back into the papermaking process as fillers, after oxidising or digesting the organic material in the sludge.¹¹⁻¹⁵ The feasibility of recovering cellulose from the sludge after fractionation has also been studied.²

One of the current value-added applications of deinking sludge is its use as raw material in the manufacture of construction materials. For example, deinking sludge is satisfactorily used to produce bricks, because it increases product quality and reduces the required burning temperature. However, the current alternative management options for its landfilling and incineration do not cope with the entire production of this waste and new alternatives, requiring further research, should be studied.^{5,16-19}

On the other hand, the fiber-cement manufacture needs new, cheap fiber sources, as a consequence of the prohibition of asbestos, which was cheap, leading to a product with optimal properties.

Earlier studies on the possible fiber sources for fiber-cement manufacture considered the use of polypropylene, glass, carbon and cellulose fibers. Nowadays, the fiber sources for fiber-cement manufacture are virgin pulps and synthetic fibers, such as polyvinyl alcohol fibers, the cellulose Kraft fibers being the most commonly used ones in the global fiber-cement production, due to their low cost, high availability and compatibility with the existing process technology.²⁰⁻²² In recent years, due to their low cost, recycled fibers have also been considered as an alternative for the fiber-cement industry, although many of them have detrimental effects on the product properties.²³⁻²⁶

The present paper studies the possible utilization of deinking sludge as a source of cellulose fibers in fiber-cement manufacture.

As a waste, its price is very low or even free, its utilization contributing to the environmental sustainability of the papermaking industry. However, compared to other sources, the quality of the fibers is quite low, as it contains more fines than fibers and as the cellulosic material is non-homogeneous. A most similar use of sludge was the one applied in 1998 by Gerischer,¹⁶ who obtained a building product from deinking sludge, fly ash and cement, which could be processed and used as a wood material. The role of the cement in this composite was only of a binder for the sludge materials.

To study the viability of deinking sludge utilization as a cellulose source, the effect of replacing the virgin pulp fibers by the fibers and fines from the sludge on both the process and product quality should be studied. The complete replacement of virgin fibers by waste fibers and fines may not be feasible, due to the low quality of the cellulosic material in the sludge, since the best fibers have been retained in the paper on the paper machine. If partial replacement of virgin fibers is feasible, this should be optimized to obtain the best fiber-cement properties, which actually represents the main objective of this paper.

MATERIALS AND METHOD

Fiber-cement specimens were prepared and their properties were measured to determine the effect of substituting part of the virgin cellulose fibers by the cellulosic material of the deinking sludge. In its absence, fiber-cement specimens were prepared from the following materials, all percentages being on a dry mass basis:

- different percentages of *Pinus radiata* unbleached Kraft fibers, 9% and 12%, refined at 450 °CSF
- 47% ASTM-type II cement
- 3.8% Al₂O₃
- 4% clay
- different percentages of standard ground silica, depending on the amount of fibers used.

The deinking sludge supplies part of the cellulose and part of the minerals. Therefore, the amounts of silica and virgin cellulose fibers were adjusted, as a function of the percentage of sludge used and on its composition. Cellulose virgin fibers were partially substituted by the fibers and fines of the sludge, and the silica was substituted

by the inorganic material of the sludge. Different substitution grades of virgin cellulose by fibers and fines of the sludge were tested: 5%, 10%, 15% and 30%. Deinking sludge obtained from a

Spanish recycling newsprint paper mill, the composition of which is shown in Table 1, was used in the experiments.

Table 1
Deinking sludge composition (% on dry mass)

Minerals (%)			Organic materials (%)		
Carbonates	Clay	Talc	Other	Fiber and fines	Other
44.1	13.86	3.15	1.89	35.15	1.85

Fiber-cement specimens of 109 g were prepared. The amount of sludge, virgin cellulose and silica used in each case was calculated by the following expressions:

Sludge as supplied:

$$Sludge = \frac{m \cdot c \cdot GS}{2109} \quad (1)$$

Mass of virgin fibers (as supplied):

$$Virg. \text{ fibers} = m \frac{c}{19.5} \left(1 - \frac{GS}{100} \right) \quad (2)$$

Mass of silica:

$$Silica = \frac{m}{100} \left[(45.2 - c) - \frac{0.378}{21.09} (m \cdot c \cdot GS) \right] \quad (3)$$

where m is the dry mass of the specimen, c is the percentage of fibers and GS is the degree of substitution of the virgin fibers by the fibers and fines from the sludge.

The water used to produce the fiber-cement mixture was tap water saturated with $\text{Ca}(\text{OH})_2$, at 21 °C.

An 100 ppm concentration of anionic polyacrylamide (PAM1) was used as an additive, to retain the minerals with the fibers. PAM1 has a molecular mass of $7.4 \cdot 10^6$ g/mol and a charge density of 1.6 meq/g. The flocculant used was a 1.5 g/L solution prepared in distilled water at 21 °C, for at least 2 h, but not more than 4 days.

For each trial, seven specimens of fiber-cement were prepared to test their properties. The specimen manufacturing procedure simulated the mill-scale fiber-cement Hatschek process. A 1 L volume of a 10% fiber-cement suspension was prepared with the raw materials mentioned above, the flocculant excluded. After mixing, it was stirred for 45 s for homogenization, prior to the addition of the flocculant. 30 s after flocculant addition, the mixture was poured into a 210 x 80 mm evacuable casting box equipped with a sieve as a filter medium. Drainage took place with a vacuum of 250 kPa. Finally, an 11 kg mass was

put on the cake for 5 s, to simulate the pressure from the cylinder former in the process, and the sheet 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 samples were prepared. Then, they were stored for 24 h in a curing chamber with water-saturated atmosphere, before curing them in an autoclave at 9 kPa and 180 °C, for 9 h. Finally, they were stored in water saturated with $\text{Ca}(\text{OH})_2$ until performing the flexural test, 7 days after the start of specimen preparation. After seven days of curing, several measurements were carried out on the manufactured specimens, *i.e.* thickness before and after breaking of the specimens, density and bending strength. The test method follows the standard EN 494; the modules of rupture (MR) were measured in the center point bending, five replications being used for each test. The other two specimens were used to measure their water absorption, which is strongly dependent on the amount and type of fibers.²⁷ The measurements involved placing the specimen in water for 24 h and weighing it after eliminating the excess water from the surface and after drying at 105 °C for 48 h.

RESULTS AND DISCUSSION

Drainage rate

Figure 1 shows the effect of substituting part of the virgin fibers by the fibers and fines from the sludge on the drainage time, during the preparation of specimens.

The drainage rate is expected to decrease as a consequence of the fines and detrimental material entering the system together with the sludge. Both this detrimental material and the fines would reduce the porosity of the specimen. However, no increase in drainage time was observed (Fig. 1), while the drainage rate actually increased when a moderate percentage of sludge was used.

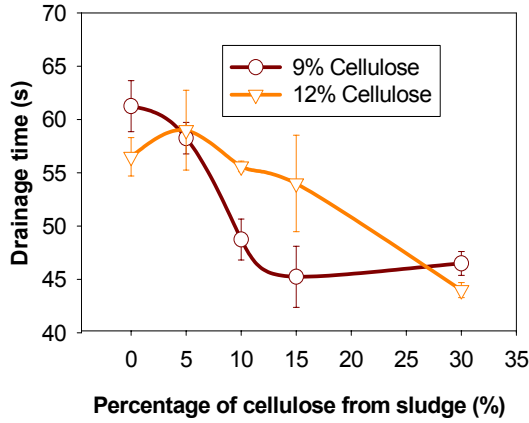


Figure 1: Effect of sludge on drainage time

Part of the detrimental material contained in the sludge could be represented by the cationic additives not retained in the papermaking process; possibly, these additives might increase drainage. However, they occur in very low concentrations, because the additives should be retained in paper. If some cationic polymers are nevertheless present, they would be neutralized by the high pH, which remained over 12, as due to the saturation of water with the $\text{Ca}(\text{OH})_2$ remaining from cement hydration. Sludge also contains fillers such as carbonates and clay that could modify the viscosity of the mixture and improve drainage. This agrees with the observation that some kinds of clays (for example, sepiolite) are used as rheology modifiers in the cement industry.²⁸

Figure 2 shows that, due to cellulose swelling, the humidity of the fiber-cement after pressing increased with the percentage of fibers. No significant effect of the sludge content was observed. Considering that the cellulose percentage remains constant at the two levels (9% and 12%), the absence of any effect means that the swelling ability of cellulose coming from the sludge is similar to the swelling ability of the virgin fibers used under experimental conditions. The virgin fiber used was unbleached softwood, while the fines were from the sludge; as they have suffered several cycles, their swelling ability was reduced. Therefore, both kinds of cellulose have a low swelling ability. During the curing stage, a part of the retained water is consumed for cement hydration, the rest

being evaporated. Consequently, voids are generated in the product and density decreases, as shown in Figure 3. The replacement of a low percentage of virgin fibers by the fibers and fines from the deinking sludge does not significantly affect these properties.

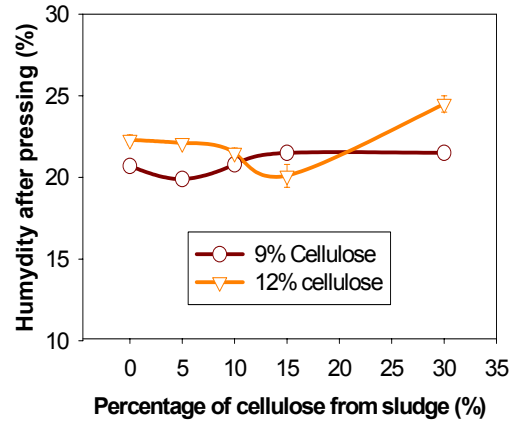


Figure 2: Effect of sludge on the humidity of the specimens after pressing

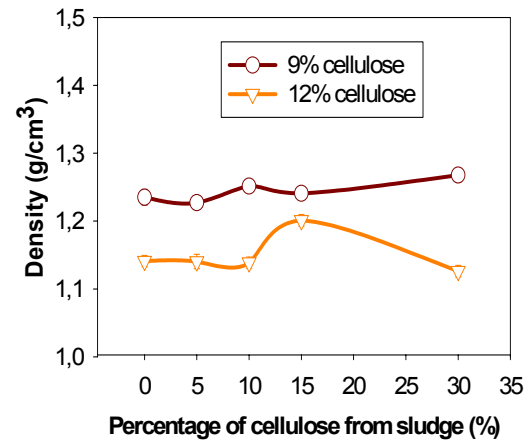


Figure 3: Effect of sludge on the density of the fiber-cement after curing

Figure 4 shows that the thickness of the specimen increased with the percentage of fibers in the fiber-cement, yet it did not significantly change when some virgin fibers were replaced by the cellulose from the sludge. The increase in thickness was also due to the increase in water retention and to the reduction in product density, as all the other dimensions of the specimens are fixed and only thickness can change with the fiber percentage.

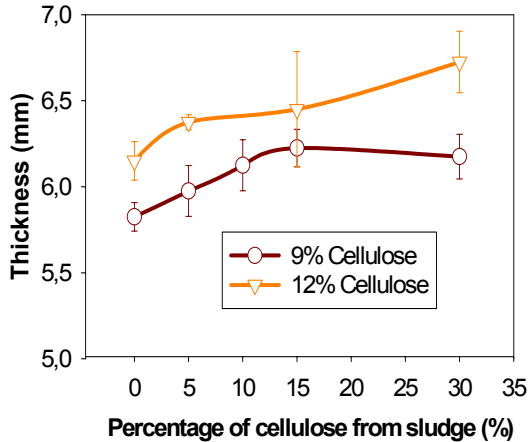


Figure 4: Effect of fibers and sludge percentages on the thickness of the manufactured specimens

Bending strength

Figure 5 shows that the breaking load of the specimens increased with the amount of fibers, which is related to the effect on thickness (the breaking load of any material usually increases with its thickness), and to the improvement of the mechanical properties, induced by the presence of fibers. Therefore, to eliminate the effect of thickness on the results, the strength module should be calculated, thus permitting a comparison of the obtained values. This module is calculated from the breaking load and specimen dimensions, by the following equation:

$$MR = \frac{300BL}{Th^2} \quad (4)$$

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

Figure 6 shows that the strength module decreased when the fiber percentage increased from 9% to 12%. The use of cellulose fibers in fiber-cement manufacture has a double effect on the fiber-cement strength. The fibers increase the links among the minerals forming the matrix of the product, thus increasing the fiber-cement strength, as well as the product flexibility. However, the cellulose fibers strongly interact with water, increasing water retention during the manufacturing process. The water evaporated during curing creates voids in the matrix, which reduce the product strength.

Furthermore, some wood compounds negatively affect cement hydration and thus decrease product strength. Figure 6 shows that maximum strength can be achieved by using 9% cellulose, of which 5% comes from the deinking sludge. In both cases (*i.e.*, at cellulose percentages in the mixture of 9% and 12%, respectively), a low percentage of sludge slightly increased the strength of the fiber-cement.

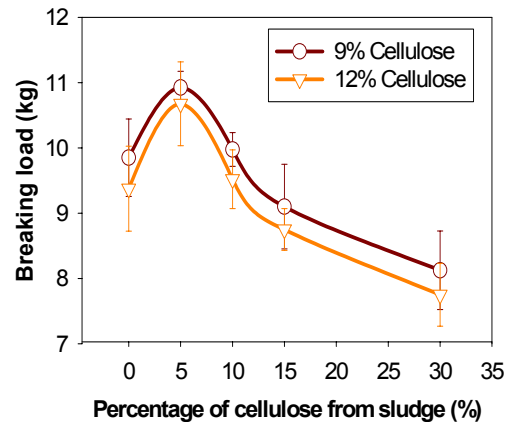


Figure 5: Effect of sludge on the breaking load of the manufactured specimens

The fibers and fines from the sludge have a specific surface area higher than that of the virgin fibers, because they are shorter and many of them are thinner. Therefore, the interaction among the fibers and fines from the sludge and the minerals could be higher than in the case of virgin fibers. Furthermore, the content of wood extractives in the deinking sludge is much lower than in the virgin pulp and, consequently, its use reduces the effect on cement hydration. Figures 2 and 3 show that these waste fines and fibers do not affect water retention, as they are cellulose, like the virgin fibers. Therefore, the replacement of 5% of the virgin fibers by the cellulose from the sludge increases the interaction between fibers and minerals, without any negative effect on water retention. This explains the effect on the fiber-cement strength for low grades of substitution.

However, the tensile strength of the fibers and fines from the sludge is lower than that of virgin fibers, which has a negative effect on the fiber-cement strength, seen as attaining important values when the

percentage of these fibers and fines in the cellulosic part of fiber-cement is over 5%.

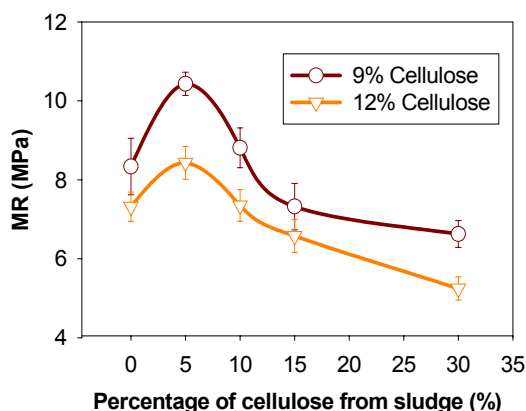


Figure 6: Effect of sludge on the strength module of the manufactured specimens

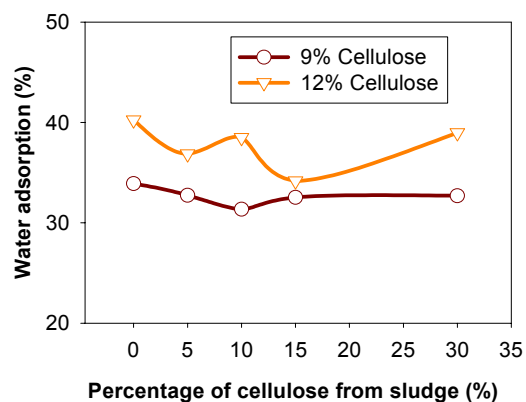


Figure 7: Absorption of water by the specimens during 24 h

Water absorption

As the fiber-cement product is used in constructions, the behaviour of the specimens in the presence of water should be studied. Figure 7 shows the humidity of the specimens after keeping them in water for 24 h. It can be observed that water absorption increases with the percentage of fibers, as due to their capability to interact with water. However, the substitution of virgin fibers by fibers and fines from the sludge does not significantly affect this property.

CONCLUSIONS

The results of this research showed that the use of deinking sludge as a source of fibers in fiber-cement manufacture might be

feasible, inducing a significant effect on both drainage and water retention, if a low amount of sludge is used. Furthermore, it could improve fiber-cement strength, if 5% of the virgin fibers are replaced by fibers from the sludge. They may also replace up to 10%, without reducing the product strength. The drainage rate could be also improved when 10-15% of the virgin fibers are replaced by the fines from the sludge.

Therefore, the present study opens a new value-added alternative for this waste, which will increase the sustainable performance of both the paper and fiber-cement industry.

ACKNOWLEDGEMENTS: The authors wish to thank the Madrid Community, for supporting the project PROLIPAPEL-CM, S-0505/AMB/0100.

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