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Bagasse-Reinforced Cement Composites

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Abstract

Bagasse is abundantly available in many countries as a by-product from sugar mills and is being mostly used as fuel or disposed of by incineration. An attempt has been made to convert this by-product into useful eco-friendly cement-bonded composites, which can be used for various internal and external applications in buildings. The investigations include optimization of parameters such as bagasse content, casting pressure and demoulding time for the production of bagasse–cement composites and the method of their production. The physico-mechanical properties of the composites produced by using the parameters finalised as above were determined. The developed composites were also subjected to accelerated laboratory tests to study the effect of moisture and alternate wetting and drying cycles on their properties. The results obtained from these studies show that the developed composites meet most of the requirements of various standards on cement-bonded particle boards and have high levels of performance even in moist conditions. Therefore, in countries where bagasse is substantially available, it can be used for the production of cement-bonded building materials.

Keywords: Bagasse reinforced cement, composite materials, particle boards, casting pressure, demoulding time, density, water absorption, bending strength, bond strength, tensile strength, durability, accelerated cycle tests, natural fibres.

INTRODUCTION

Revolution in the agricultural sector has resulted in substantial increases in the quantities of agricultural by-products and wastes of different types. In addition to reed, straw, corn cob and stalk, many other non-traditional materials, such as coir fibre, bagasse, coconut pith, ground nut husk, rice husk and jute sticks, are obtained as agro-wastes. They are mostly disposed of by incineration or used as fuel, although their calorific value is much lower than that of coal. Utilization of these agro-wastes, apart from solving the problem of their disposal would improve the agricultural economy considerably. The building industry has the maximum potential for the utilization of these materials through their conversion into various kinds of building panels and blocks, as they provide a low cost source of reinforcing materials for cement-bonded products. Panels and blocks prepared from agro-industrial wastes have the advantage of being light in weight and possess good thermal insulation properties.

Bagasse is abundantly available in India as a residue from sugar mills. Presently a major portion of bagasse is used as fuel for generating steam, though few particle board industries have also started using it as a raw material in place of wood particles for the manufacture of resin bonded particle boards. Investigations were, therefore, initiated for the development of composites using bagasse particles and cement. The effects of fibre content, casting pressure and demoulding time on the properties of bagasse reinforced cement samples were studied and parameters for their production optimized. The various physico-mechanical properties of the developed composites were determined. Accelerated laboratory tests were also carried out to see the effect of moisture and weathering on the developed composites. The results obtained from the above studies are reported in this paper.

EXPERIMENTAL PROGRAMME

Materials and sample preparation

Bagasse is the residue left after the crushing of sugar cane for juice extraction. The upper layer of bagasse consists of a hard fibrous substance while the inside is soft material generally called pith which is a non-fibrous material having practically no strength. In dry bagasse, hard fibrous content is about 65% and 35% pith. Bagasse after the removal of pith is resistant to decay.

The bagasse particles used in the present investigations were procured from a commercial unit manufacturing resin bonded particle boards. Some important properties of the bagasse particles are given in Table 1. Ordinary Portland cement conforming to IS: 269-1979[1] was used. All other chemicals used were of commercial grade.

Samples were prepared by varying the bagasse content (0–20% by mass), casting pressure (1·0–5·0 N mm^{-2}) and demoulding time (1–10 h) following the procedure described hereafter. Bagasse particles were soaked in water containing chemical admixture for 2 h, after which unabsorbed water was drained off. The bagasse particles were then thoroughly mixed with Portland cement. A water/cement ratio of 0·40 was used. The cement coated bagasse particles thus obtained were uniformly spread in a steel mould (300 × 300 mm size). Steel plungers were put in to the mould and the mixture was pressed hydraulically. The whole assembly of the mould and plunger was kept in the pressed position for varying periods to optimize the time required for the bagasse–cement mix to attain strength so that the mix would not undergo any spring back action, i.e. there was no variation in the thickness of the consolidated mass after the pressure was released. The samples thus obtained were demoulded, moist cured for 10 days and finally air dried.

Table 1. Typical properties of bagasse particles

Colour	Light brown
Grading of particles % retention at:	
2·36 mm	1–2
1·18 mm	50–55
600 μm	36–40
150 μm	9–10
Bulk density (kg m^{-3})	180–190
Water absorption (%)	250–280
Ash content (%)	3–4

Test methods

Density, water absorption, thickness swelling, bending strength and internal bond strength (tensile strength perpendicular to plane of board) were determined to study the effect of various parameters mentioned earlier on the bagasse–cement samples. The samples were tested for various properties following the procedures described in ISO: 8335-1987[2] and IS: 2380-1977.[3] Density, water absorption and thickness swelling were measured by using 100 × 100 mm strips, whilst 300 × 75 mm rectangular strips were used for bending strength and 50 × 50 mm strips to determine bond strength of samples.

The bending strength was measured in three point loading using a span of 200 mm at a deflection rate of 5 mm min^{-1} on a Zwick Testing Machine (Model 1474). Water absorption and thickness swelling values were obtained by immersing the samples in water for 24 h. Internal bond strength was determined at the crosshead speed of 1 mm min^{-1}.

The accelerated durability programme included a water immersion test up to 720 days of immersion in water and exposure of the samples to an accelerated cyclic test specified in IS: 2380-1977[3] and IS: 12406-1988.[4] In brief, one cycle comprises of the following steps: 72 h immersion in water at 27 ± 2°C + 24 h drying in air at 27 ± 2°C and 72 h heating in dry air at 70 ± 1°C. The accelerated cyclic test is similar to the accelerated aging test reported in the literature with one change, i.e. in the present studies samples were kept at 27 ± 2°C for 24 h instead of −12°C mentioned in the V313 test.[5]

In all cases, at least six samples were tested for density, water absorption, thickness swelling, tensile strength, internal bond strength and bending strength and the mean value for all these properties are reported.

TEST RESULTS AND DISCUSSION

The effect of change in casting pressure on density and water absorption of bagasse–cement samples is shown in Figs 1 and 2. The variations in density, water absorption, bending strength and internal bond strength of samples with increase in bagasse loading are shown in Figs 3–6. The increase in water absorption of the samples with time is shown in Fig. 7.

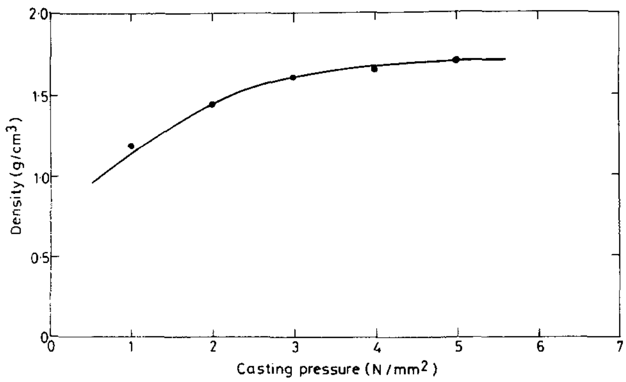

Fig. 1. Casting pressure vs density (16% bagasse).

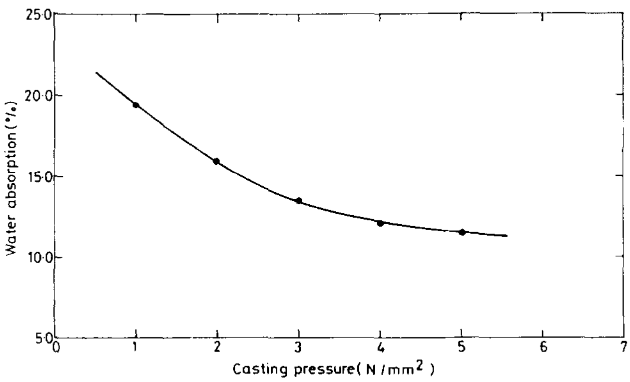

Fig. 2. Casting pressure vs water absorption (16% bagasse).

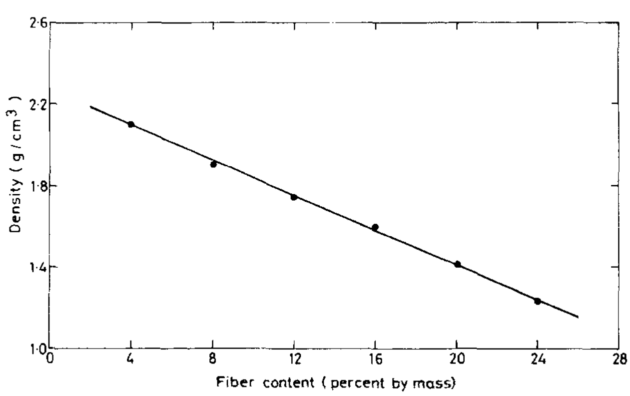

Fig. 3. Fiber content vs density.

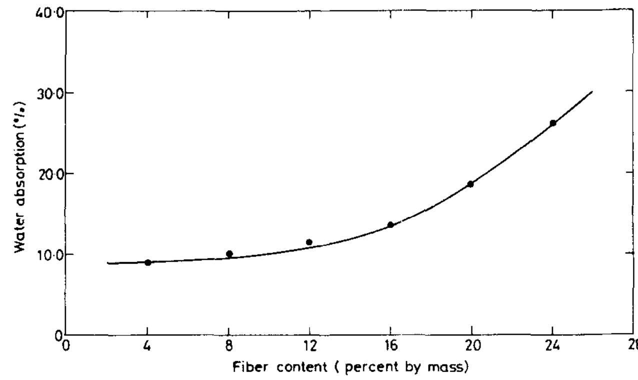

Fig. 4. Fiber content vs water absorption.

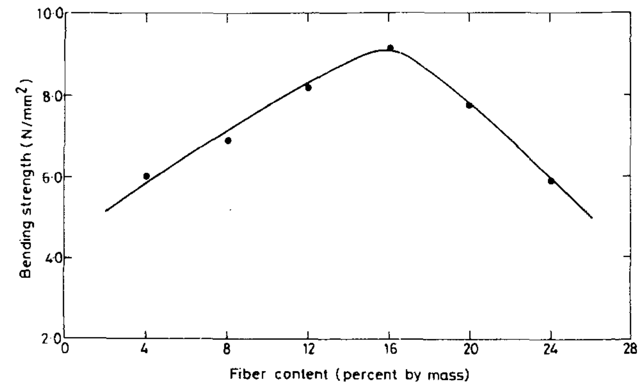

Fig. 5. Fiber content vs bending strength.

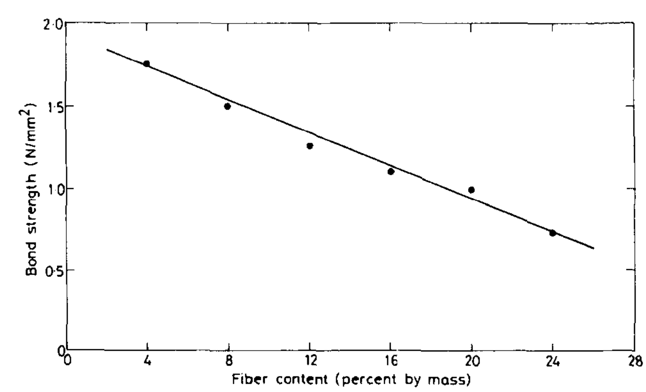

Fig. 6. Fiber content vs bond strength.

Effect of casting pressure

The change in density and water absorption of bagasse–cement samples containing 16% bagasse by mass with increase in casting pressure is shown in Figs 1 and 2. In fibre-reinforced composites, the increase in casting pressure results in the formation of more compacted fibre–cement mass, thereby decreasing the void volumes within the samples and hence the thickness of the consolidated mass. The decrease in void volumes within the samples has a dominant effect on the density, water absorption and strength properties of the samples. In the case of bagasse–cement samples there was a continuous increase in density with the increase in casting pressure. It was observed that when the casting pressure was increased from 1·0 to 3·0 N mm^{-2}, there was about 32% increase in density (1·21–1·60 g cm^{-3}) of the consolidated mass while 7·5% (1·60–1·72 g cm^{-3}) increase was observed when the casting pressure was increased from 3·0–5·0 N mm^{-2} for the same volume of bagasse–cement mix.

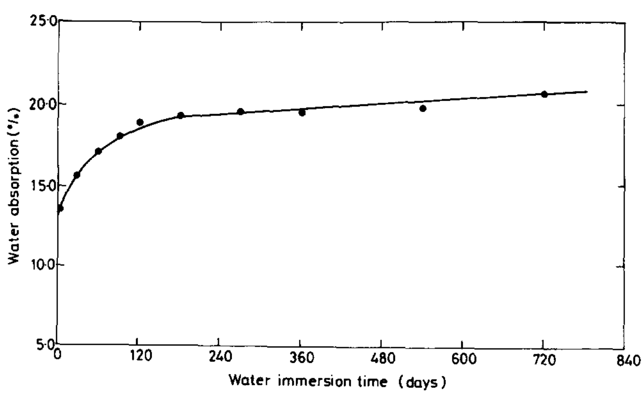

Fig. 7. Water immersion time vs water absorption.

The decrease in water absorption of the samples is from 19·5 to 13·4% and 13·4 to 11·6% when the casting pressure is increased from 1·0 to 3·0 N mm^{-2} and 3·0 to 5·0 N mm^{-2}, respectively. The present studies showed trends similar to those reported in the literature[6] for fibre-reinforced composites, i.e. an increase in casting pressure resulted in higher density and lower water absorption values (Figs 1 and 2). It can be concluded from the above results that the optimum casting pressure required for bagasse–cement samples is in the range of 2·0–3·0 N mm^{-2}.

Effect of bagasse content

The effect of change in bagasse content on the density, water absorption, bending strength and internal bond strength of bagasse–cement samples cast at 3·0 N mm^{-2} pressure is shown in Figs 3–6. The increase in percentage of bagasse in the bagasse–cement mix decreases the density of the samples (Fig. 3) while the water absorption values increase (Fig. 4). The replacement of cement (dense material) by bagasse (lighter material) resulted in an increase in total volume of the mix even after compaction at 3·0 N mm^{-2} pressure, as was indicated by the increase in thickness, i.e. volume of the samples increases with the increase in bagasse content. Further, the increase in volume of the compacted mix is directly related to the increase in bagasse content in the mix. This increase in volume of the compacted mix resulted in a decrease in density of the samples (Fig. 3), an increase in their thickness and water absorption (Fig. 4). It was observed that there is a sharp increase in water absorption when the bagasse content in the mix is more than 16% by mass.

The bending strength of the bagasse–cement samples increased with increase in bagasse content up to 16% by mass and further increase in bagasse content resulted in a lowering in bending strength (Fig. 5). It was found that when the cement matrix was loaded with 4, 16 and 24% bagasse content, the bending strength of the matrix first showed an increase from 6·04 to 9·21 N mm^{-2} and then decreased from 9·21 to 5·86 N mm^{-2}. The decrease in bending strength at higher bagasse content in bagasse–cement mix can be explained as follows. The development of strength properties in fibre–cement mix, apart from tensile strength of fibres, mostly depends on the formation of fibre–matrix, matrix–matrix and fibre–fibre bonds, i.e. their ability to bond to matrix and/or to each other. The bonding can be affected by dimensions, surface conditions and number of fibres present in a given volume of material.[7] In case of bagasse–cement samples, the optimum conditions are obtained when the bagasse content in the mix is in the range of 12–16% by mass. Further, increase in bagasse content has adverse effect on the samples and results in lower than expected strength properties. The decrease in bond strength with the increase in bagasse content in the bagasse–cement mix confirms the above mentioned observations (Fig. 6).

On the basis of these studies, the optimum parameters for the production of bagasse–cement composites are bagasse content 12–16% by mass, casting pressure 2–3 N mm^{-2} and demoulding period more than 6 h depending upon the temperature and humidity of the production yard. The composite samples were prepared by using 16% bagasse content using 3 N mm^{-2} casting pressure following the method described earlier. The bagasse–cement composite samples were evaluated for various physico-mechanical properties following standard testing methods. The results obtained are given in Table 2, which show that the developed composite samples conform to the requirements laid down in ISO: 8335-1987[2] and BS: 5669: Part 4-1989[8] for cement-bonded particle boards.

Accelerated laboratory tests

The effect of long term field exposure on the performance of bagasse–cement samples was investigated through accelerated laboratory tests. The samples used for these studies were produced by using 16% bagasse by mass in bagasse–cement mix and 3·0 N mm^{-2} casting

Table 2. Properties of bagasse–cement composites

Density (kg m^{-3})	1550–1650 (1000, min)
Moisture content (%)	6·5–6·8 (6–12)
Water absorption (%)	12·5–14·5 —
Thickness swelling (%)	0·30–0·46 (2, max)
Bending strength (N mm^{-2})	8·85–9·60 (9, min)
Tensile strength (N mm^{-2}) (Perpendicular to plane of board)	1·06–1·14 (0·45, min)
Tensile strength (N mm^{-2}) (Parallel to plane of board)	1·58–1·71 —

Values given in parentheses correspond to ISO: 8335-1987[2] and BS: 5669: Part 4: 1989.[8]

Table 3. Properties of bagasse–cement composites exposed to accelerated cyclic test

Property	*Number of cycles* 0	*3*	*6*	*10*	*15*	*25*
Thickness (mm)	11·96	11·98	12·01	12·05	12·10	12·14
Thickness swelling (%)	0·346	0·348	0·362	0·475	0·631	0·765
Water absorption (%)	14·05	14·16	14·28	14·85	15·70	16·45
Internal bond strength (N mm^{-2})	1·10	—	1·09	1·04	0·98	0·94
Visual obervations for delamination disintegration or cracking	—	No	No	No	No	No

pressure. The various properties of the samples subjected to accelerated laboratory tests were determined following the methods described earlier.

Water immersion test

The increase in water absorption of bagasse–cement samples with time is shown in Fig. 7. There is a sharp increase in water absorption up to 120 days (13·4–18·8%) but then the increase in water absorption is comparatively small, 20·6% after completion of 720 days of water immersion.

The water immersion test was conducted to study the long term effect of moisture on the properties of bagasse–cement samples due to sensitivity of cellulosic materials to moisture. The effect of moisture on the particle or fibre reinforced cement samples can result in the leaching of water solubles present and/or their decomposition into low molecular weight lignins, hemi-celluloses or other degradation products resulting in the breakdown of fibres or particles. There is also the possibility of disruption of bonding of fibres and the matrix in the composite during prolonged exposure of samples to moisture. All these effects would ultimately result in the disintegration, delamination, cracking and/or swelling of samples, thereby affecting their performance characteristics. In the case of bagasse–cement samples, it was observed that after 720 days of water immersion the density of samples decreased from 1·645 to 1·640 g cm^{-3} and the change in thickness was 1·02–1·68%. This increase in thickness after 720 days in water immersion is less than the increase in thickness after 24 h of immersion, i.e. 1·8%, permissible as per BS: 5669: Part 4: 1989.[8] Moreover, on visual observations it was found that there were no signs of delamination, disintegration or cracking of samples. It can be inferred from the above mentioned observations that bagasse–cement composites have high levels of performance in the presence of moisture.

Accelerated cyclic test

In the course of natural weathering the cellulosic content of the cellulosic-cement composites will be exposed to repeated wetting and drying cycles (rain and heat conditions) which promote the physical and mechanical mechanism of deterioration of composites.[9] These conditions also accelerate any potential attack by the alkaline pore water of cement based materials and migration of some cement-hydration products from the matrix into the fibre cores and their interfacial zones.[10,11] These changes would result in alternate swelling and shrinking of fibres, breakdown of fibres and/or disruption of the fibre matrix bond[12] which would ultimately affect the engineering properties of aged composite samples. In the present studies, the accelerated cyclic test was carried out by subjecting the samples to alternate wetting and drying cycles described earlier. The results obtained after 3, 6, 10, 15 and 25 cycles of exposure are given in Table 3. The effects on the properties of bagasse–cement samples after 10 and 25 cycles of exposure are increase in thickness of samples from 11·96 to 12·05 and 12·14 mm and water absorption from 14·05 to 14·85 and 16·45%, respectively. The thickness swelling value of samples increases to 0·765% while the internal bond strength decreases from 1·10 to 0·94 N mm^{-2} after 25 cycles of exposure. However, the thickness swelling and internal bond strength values obtained even after 25 cycles of exposure are very much within the limits specified for cement-bonded particle boards in BS: 5869 Part 4: 1989.[8] The reduction in internal bond strength of samples exposed to accelerated cyclic test indicates the possibility of breakdown of the fibres and/or disruption of bagasse–cement bonds due to alternate swelling and shrinking of bagasse particles. The disruption of bagasse–cement bonds might have resulted in the increase in thickness and water absorption of samples after 25 cycles of exposure (Table 3).

It can be inferred from the above studies that the bagasse–cement composites conform to the requirements laid down in ISO: 8335-1987[2] and BS: 5669: Part 4: 1989[8] for cement-bonded particle boards. The composites show good resistance to moisture and alternate wetting and drying cycles and therefore should be durable in service.

CONCLUSIONS

(1) Bagasse can be used for the production of cement-bonded composite materials.
(2) The optimum parameters for the production of bagasse–cement composites are: bagasse content 12–16% by mass, casting pressure 2–3 N mm^{-2} and demoulding time more than 6 h.
(3) The developed composite material conforms to the requirements laid down in ISO: 8335-1987 and BS: 5669 Part 4: 1989 for cement-bonded particle boards.
(4) Bagasse–cement composites show high levels of performance in the presence of moisture and alternate wetting and drying cycles and therefore can be recommended for both internal and external applications in buildings.

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