20th WEDC Conference
AFFORDABLE WATER SUPPLY AND SANITATION
Colombo, Sri Lanka, 1994

Natural fibre reinforced concrete blocks

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WHILST NATURAL FIBRES have been used to reinforce construction materials since time immemorial (the use of straw in sun-dried mud bricks or the strengthening of mortar with horse-hair being typical examples) study into their use in cementitious mixtures seems to have gained popularity only in the last twenty years or so. However, although some progress has been achieved, most notably with roof tiles and roof sheets, the loss of strength due to deterioration of the fibres has given cause for concern. Despite this drawback, the apparent success of natural fibres in economic housing applications elsewhere encouraged investigation of their potential use in South Africa where the need to address the critical housing requirements of the previously disadvantaged population was strikingly obvious from the number of squatter camps mushrooming around our towns and cities in recent times.

A research programme was therefore initiated to investigate some of the possible local uses of natural fibre cement composites (a collective term including concrete) in mass housing applications (Stephens, 1993). This programme has recently been given an even greater impetus and focus by the decision of the new Government of National Unity to make one of its major goals the provision of 1 million new houses within the next five years. This could make natural fibre cement composites an immediate and important area for potential cost savings as the finance needed to accelerate this new housing (and the complementary services required) will put the national budget under considerable strain for many years to come and any means to reduce building costs such as by the use of these composites would obviously be welcomed.

Usage of natural fibres

In their comprehensive summary of the use of natural fibres in cement composites, Aziz *et al* (1984) reported that coconut coir, sisal, sugarcane bagasse, bamboo, jute and wood cement composites had already been investigated in more than 40 countries world-wide. Studies of other fibres such as pissava and henequey have since been reported by other authors including Agopyan (1988).

Whilst many of these fibres are obtainable in South Africa, sugarcane bagasse was selected for preliminary study in the research programme for three main reasons. Firstly, bagasse is widely and cheaply available along the Natal coast on the Eastern seaboard of South Africa where the University of Durban-Westville is located; secondly, there are close connections between our university and the sugar growing industry in Natal and any useful research results would thus have benefit for both parties; and finally, the actual fibres have already been through a refining process in the sugar mills where they are cut to usable lengths and most of the deleterious solids removed, meaning that very little pre-treatment (if any) would be needed before the fibres could be used in natural fibre cement composites. One possible drawback of investigating bagasse was that this fibre had not been as extensively researched as other natural fibres in the past (although this of course did present more scope for original research), as reference to the literature showed that there was little data on the use of these fibres in cement composites apart from the work of Racines and Pama (1978) who had only dealt with pressure-cast thin sections.

Previous applications

Although natural fibre cement composites could be used in almost as many applications as those with man-made fibres, not all of the potential uses seem to have been investigated thus far. Conversely, some of the earlier enthusiastic proposals for their use do not appear to have survived application testing, possibly due to the fibre durability problems discussed below. Two major areas researched to date are what could be termed “high” and “low” percentage fibre mixes. The composites in the former group consist mainly of thin roof sheets which have a proportion of fibre up to about 30 percent by volume, whilst the latter consist of cement mortar or concrete matrices with between one and three percent fibres by volume. These latter composites have been used mainly in roofing tiles. Both products are generally pressure cast, although vibrating tables have also been used for roofing sheets with acceptable results.

The problem of durability

Some authors, notably Gram (1988), had indicated that problems experienced with the poor durability of fibres in some reinforced cement composites were probably due to alkali attack of the fibres by the pore water present in the cement matrix. Suggestions to resist this deterioration included changing the alkalinity of the pore water, replacing part of the cement with silica fume, using natural pozzolans in the mix or by sealing the pore system using additives in the mix or impregnating it with sulphur. One of the pozzolans which has already being examined is rice husk ash (Gram and Nimityongskul,1987) although (most interestingly for the current research) it has been suggested that sugarcane bagasse ash could also be used as it has a high silica content and thus might display similar pozzolanic properties.

It was therefore obvious that the problem of fibre durability might well delay the production of any positive results from the research programme, particularly as no real success appeared to have been gained using the proposed protection methods. Therefore in order to build up momentum in the research programme by investigating applications in which the fibre durability problem could probably be ignored, efforts were made to identify those areas in which only short term fibre strength was required. An early candidate in this search was the reinforcing of concrete masonry blocks with natural fibres where it was proposed that long term fibre strength was not of major importance as the anticipated improved tensile and impact strengths they provide would only be required temporarily during manufacture, transportation to site and laying in position in the final structure. Once laid, only compressive strength would be required in the blocks.

Concrete masonry blocks

Raath (1993) had proposed that the typical compressive strengths specified for concrete masonry blocks could be reduced for economic housing applications where the maximum loads on the blocks would probably be lighter than those apparently assumed in the standard specifications. He particularly felt that the worst loads the blocks would suffer were during their transportation to site.

As manufacturing and transportation loads on these blocks are generally tensile or impact in nature, it is probable that the typical standard specifications for these blocks (eg SABS, 1984), which grade the blocks in respect of compressive strength alone, stipulate higher compressive strengths than actually required to ensure that the blocks attain the required tensile and impact strengths to resist the forces they will be subjected to in manufacture and transportation. Thus if natural fibres could provide increased tensile and impact strengths, even temporarily, the quoted compressive strengths could be lowered with a commensurate reduction in the cement concrete of the mix. As cement is a large component in the manufacture of these blocks, a significant cost reduction could be expected, as the fibre is a waste product.

Laboratory work

The sugarcane bagasse fibres used in this investigation were obtained from the Gledhow sugar mill near Tongaat some 75 km Northeast of Durban. The Gledhow bagasse is de-pithed by machine at the mill for use in a neighbouring pulp and paper plant where the pith is not permitted in the papermaking process. Other sugar mills do not de-pith their bagasse as it is normally used for fuel in the furnaces to provide steam for the refining process where the pith can be burnt as well. Pith is the weak powdery material which remains in the bagasse after the sugar has been extracted (Racines and Pama, 1978) and its removal can prove to be a laborious process when done by hand in the laboratory. Sugar content tests on bagasse had shown a residue of about 0,02 percent sugar by mass in the fibres which would not cause any retardation in the setting of concrete, particularly at the low fibre percentages used in the concrete mixes (PCI, 1986).

One major problem encountered with bagasse fibres is that the fibre lengths resulting from the refining process vary quite substantially. Some selection was therefore required to obtain a reasonably narrow spread of typical lengths somewhere close to the optimum length, which had been shown in previous work by Mansur and Aziz (1981) on jute fibres to be approximately 25mm. After many attempts at finding a simple method of selection, recourse was finally made to simple sieving. It was found that by lightly hand shaking the fibres through 300mm diameter sieves the fraction passing the 9,5mm diameter sieve and retained on the 4,75mm sieve gave a reasonably narrow spread of fibre lengths normally distributed around a mean of 25mm. Whilst there are limitations to this method, particularly in terms of repeatability, it appeared to be a suitable compromise compared to the only other feasible time-consuming options of individual hand selection or cutting fibres to length. In any case, the selection method was only sought to obtain fibres for use in showing whether or not improvements in tensile and impact strengths of concrete could be achieved in the concrete block mixes, and refinement of the method could be carried out at a later stage.

Little guidance was available to assist in choosing a target concrete strength (and thereby the relevant mix proportions), as most of the previous work by others had related to higher strength concretes. The standard South African specification (SABS, 1984) quotes a minimum nominal compressive strength for concrete masonry blocks of 3,5 N / mm^2 but as the current research was designed to reduce this by adding fibre reinforcement, the target 28-day compressive strength was taken as 1 N / mm^2 for initial purposes, and the required cement-to-water ratio extrapolated at approximately 0,5 according to the Portland Cement Institute's method of mix design (PCI,1986). Plain river sand was used as the aggregate and a trial-and-error process followed to find the optimum amount of water (and thereby cement) to be placed in the mix to give a satisfactory initial slump (and thus workability). The optimum cement to sand ratio arising from this process was found to be approximately 1:10.

The work by Racines and Pama (1978) could not be used to obtain a first estimate of the optimum fibre percentages to be added to the mix, as their work related to the "high" percentage fibre mixes mentioned above. However, researchers working with low percentage fibre mixes on other types of fibre (reported by Swamy, 1984) had shown that an optimum value might be in the region of 2 percent by volume. Three percentages were therefore initially used namely 1, 2 and 3 percent fibre by volume. As the initial mix had to be adjusted to allow for the addition of these fibres it was necessary to find the bulk density of the fibres. Other researchers (see Swamy, 1984) had obtained values for specific gravity of bagasse fibres between 1,2 and 1,3 but these probably referred to the constituent material of the fibres and not their structure, as dry bagasse fibres float on water indicating a bulk density less than one. An approximate value of 0,5 (considered adequate for preliminary purposes) was eventually found by using a density bottle. Trial mixes were made to ascertain the workability of the three mixes and it was found that the standard slump cone test gave slumps ranging from 80mm for the unreinforced mix down to 35mm for the mix with 3 percent fibres which was considered to be acceptable. The final mixes used are shown in Table 1.

The possibility that the dry fibres would take up water and thus reduce that available for hydration of the cement in the concrete mixes was investigated, but preliminary tests suggested that this problem would not be of major consequence provided the fibres were first well mixed with the aggregate and cement. The optimum method of mixing (which satisfied the above requirement and also gave the most homogeneous mix) was found to be to first mix the sand and cement thoroughly in the mixer, add the fibre in a steady stream by hand, and then finally the required amount of water (adjusted for hygroscopic water in the sand aggregate). A small (250 litre) tilting-drum concrete mixer was used to mix the concrete and performed this task adequately.

Preliminary work on fibre reinforced mortars had indicated that if the resulting cubes were cured under water in the standard fashion, moisture in the fibres detrimentally affected the bond between the concrete matrix and the fibres and thereby reduced the tensile strength of the reinforced mortar. Therefore cubes from each mix were either cured in water or air to ascertain the extent of any differences in strength. The time development of concrete strength was also investigated and a series of 150mm cubes were manufactured for tensile testing at 14, 42, 56 and 84 days (28 day tests could not be carried out as some of the tests would have fallen during a holiday period). A set of 28 day compression tests was, however, carried out as a control on 150 mm cubes made from the four mixes and to give a comparison with the tensile tests. Limited impact tests were also carried out on 100 mm cubes, three for each mix.

Compression tests on the cubes followed the South African standard method (SABS, 1976) and tensile tests the British Standard method (BSI, 1983). Impact tests were not carried out to any standard method, an empirical one being employed whereby the 100 mm cubes were repeatedly dropped onto the concrete laboratory floor from a height of 1 metre and the number of drops to destruction recorded. Whilst crude, this method appeared reasonably effective and the results achieved were considered satisfactory for comparison purposes. Trials of a Schmidt hammer to quantify impact resistance were unsuccessful due to the low strength of the concrete, which hardly registered any reading on the hammer's scale after impact.

Results

Table 2 shows that the compressive strength of the unreinforced mix at 28 days was 1,34 N/mm^2 which compares favourably with the target strength of 1 N/mm^2. Table 2 also shows that the compressive strength of air cured reinforced cubes with 1 percent fibres was actually marginally higher than the unreinforced concrete and only slightly less for two and three percent fibres.

The tensile test results in Table 3 indicate that the highest tensile strengths were obtained in the mixes with one percent fibres in both water and air cured conditions.

The difference between water and air curing of the reinforced test cubes is well illustrated by Figure 1 which graphs the results for concrete with one percent fibres. At 28 days the air cured concrete was approximately 24 percent stronger in tension than the water cured one, although by 84 days this gap had reduced to about 18 percent. By comparison, Figure 2 shows that - as would be expected - the reverse situation is obtained for the unreinforced cubes.

The results of impact testing in Table 4 relate to one series of 100 mm cubes (three cubes per mix) which were tested at an age of 84 days. As explained above, the test method is crude but the results are consistent enough to indicate that there is a substantial increase in impact resistance with fibre reinforcement and that this is higher for higher percentages of fibres in the mix.

Discussion

Figures 1 and 2 show that air cured concrete reinforced with one percent fibres by volume is almost 49 percent stronger in tension than the air cured unreinforced concrete and 34 percent stronger than the water cured unreinforced concrete. Whilst it could be debated which of these increases should be quoted it is really of academic interest only as the most important outcome was that an actual increase in tensile strength was obtained in both cases which gives a basis for further investigations into the application of bagasse fibres in actual concrete blocks. This improvement was more than matched by the increases in impact strength whereby the reinforced mixes resisted up to three times the damage inflicted on the unreinforced one before reaching destruction.

Further research is now under way to apply the above findings to the manufacture of actual concrete blocks. An immediate part of this work will entail ascertaining what individual contributions the tensile and impact strengths of the concrete make to the overall resistance of the blocks

Table 1. Mix proportions.

Mix reference	A	B	C	D
Percent fibres (vol)	0	1	2	3
Cement	1	1	1	1
Water : cement	2	2	2	2
Sand : cement	10	9,84	9,67	9,51

Table 2. 28 day comprehensive test results.

Mix reference	A	B	C	D
Percent fibres (vol)	0	1	2	3
Comprehensive strength (N/mm^2)	1,34	1,37	1,32	1,27

Table 3. Tensile test results.
(N/mm^2 at age in days shown)

Mix reference	A	B	C	D
Percent fibres (vol)	0	1	2	3
(a) Water cured				
14 day strength	0,23	0,25	0,17	0,17
42 day strength	0,32	0,36	0,15	0,21
56 day strength	0,32	0,32	0,19	0,20
84 day strength	0,40	0,38	0,24	0,23
(b) Air cured				
14 day strength	0,23	0,34	0,15	0,19
42 day strength	0,29	0,41	0,20	0,18
56 day strength	0,29	0,39	0,20	0,17
84 day strength	0,32	0,41	0,23	0,21

Table 4. Impact resistance.

Mix reference	A	B	C	D
Percent fibres (vol)	0	1	2	3
No. of 1m drops to destruction	5,67	10,3	12,0	16,0
Percentage improvement on plain mix	-	81	211	282

Figure 1. Tensile strength vs age : 1% reinforced mix.

Figure 2. Tensile strength vs age : unreinforced mix.

to damage in manufacture, transportation and placing, as this has a direct influence on the amount of fibre to be added. For example, if tensile strength is relatively more important, then a lower fibre percentage would be advisable, whereas if impact resistance is more important then a higher percentage would be indicated, although workability might become a controlling factor in this case.

Acknowledgements

The author wishes to thank the original leader of this project, Professor B K Dougherty, for his thorough preparatory work and overall guidance. Mr B Raath of the Portland Cement Institute has provided valuable advice at many stages during the planning of this research. The assistance of the Foundation for Research and Development in providing a grant for this project and that of the

University of Durban-Westville in making the author's attendance at the conference possible is also gratefully acknowledged.

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