A PROCEDURE FOR PROCESSING MIXTURES OF SOIL, CEMENT, AND SUGAR CANE BAGASSE

R. Medjo Eko
Lecturer, Department of Agricultural Engineering
Faculty of Agronomy and Agricultural Sciences
University of Dschang
Dschang, Cameroon
rmedjo@yahoo.com

G.L. Riskowski
Professor, Agricultural Engineering Department
University of Illinois at Urbana-Champaign
Urbana, Illinois USA
griskows@uiuc.edu

ABSTRACT
Two schemes for processing mixtures of soil, cement, and sugar cane bagasse have been investigated to determine the best way of processing house construction bricks for rural Africa. In one case, bagasse fibers were treated for removing sugar while untreated bagasse fibers were used in the other one. Processing house construction bricks from soil, cement, and untreated bagasse turned out to be the best scheme. A check of sugar content in the best scheme showed that sugar content was higher than critical sugar content (0,5 g/l) that hampers cement hydration in concrete based materials; but unexpectedly, cement hydrated in this scheme. Cement hydrated in these mixtures because sugar from untreated bagasse fibers evolved to the form of polysaccharides; these molecules are known to bind soil particles together. This study shows that it is not necessary to treat bagasse fibers prior to mixing it with soil-cement while processing house construction bricks.

Key words: bagasse, soil-cement-bagasse mixture, unconfined compressive strength, lime stabilization.

INTRODUCTION
Quick setting and strength gain are the properties that make Portland cement a desirable binder in the construction industry. These properties are so important that hydration, the process during which they occur, and factors affecting it have been extensively studied over the years. One of these factors, sugar, has been found to delay the setting of cement hydration. The agreement about that has led investigators to all have the same routine. Whenever they plan to mix a material containing sugar with cement, the first step is to remove the sugar using the most effective scheme.

Sera et al. (1990) studied the effect of reinforcing concrete with bagasse fibers. They boiled bagasse fibers in water for 30 minutes to remove the sugar prior to using it as reinforcement.

Bagasse is a fibrous residue obtained from sugar cane during extraction of sugar juice at sugar cane mills. Sugar processed from sugar juice is used for human consumption and other current purposes.

Shokry et al. (1992) investigated the possibility of making a lightweight masonry unit from concrete reinforced with white spruce sawdust. They used two experimental schemes to remove sugar from white spruce sawdust. The first consisted of soaking it in cold water for 3 days prior to use; the second scheme consisted of boiling it in water for 3 hours prior to use. They chose to use the cold water scheme because there was no difference between the hydration products from the two schemes. Furthermore, the cold water treatment was less energy intensive.

Because of reduced financial resources, a major part of African rural population uses local building materials for erecting houses. Soil is the basic material for this purpose because it is available everywhere in rural areas. It is mainly used for making house mud walls and house construction bricks. When some financial resources are available, house owners sometimes mix soil with natural fibers and a certain amount of cement..

This study has been undertaken as a preliminary phase of an investigation aimed at studying the structural behavior of house construction bricks made out of soil-cement-sugar cane bagasse mixtures (Medjo and Riskowski, 1994). The research shows that Portland cement hydration occurs in soil mixed with sugar cane bagasse which has not been previously treated for removing sugar.

BACKGROUND

Sugar is used as a set-retarding admixture in concrete. It slows down the rate of early hydration of C_3S by extending the length of the cement dormant period. The extension of the dormant period is proportional to the amount of retarding admixture used. When concentration of sugar exceeds 0,5 g/l of concrete, the C_3S hydration will never proceed beyond the dormant period and the cement paste will never set (Mindess and Young, 1981). In the United States, truck drivers carrying unset concrete in situations where setting must be delayed often take advantage of this fact by adding a bag of table sugar to the concrete batch.

MATERIALS

The materials consisted of ASTM Type I Portland cement, leachate yellowish soil, bagasse fibers, and tap water. The grain size distribution of the soil is displayed at figure 1. It was carried out according to ASTM D 422-63. Atterberg limits done according to ASTM D 4318-95a yielded a Liquid Limit of 27.50 and a Plasticity Index of 4.75. Interpretation made using Atterberg limits and soil analysis data led to the conclusion that the soil was a silty sand and could be classified as A-2-4 in AASHTO (American Association of State Highways and Transportation Officials) classification. Soil compaction tests carried out according to ASTM D 698-91 showed that soil optimum moisture content was 17.75 % and its maximum dry density was 1750 kg/m^3 (figure 2).

The average length of bagasse fibers was 80 mm and their average thickness was 0,2 mm. Bagasse fibers were collected from a sugar cane mill in Saint Martinville, Louisiana, USA. The soil was also gathered from the same location. Both were stored in closed plastic bags for seven months at a room temperature of 22 °C and relative humidity of 60-70 % prior to use. Two types of bagasse were used: one was treated to remove sugar and the other was untreated. Bagasse treatment consisted of boiling it in water for 90 minutes, then washing it in warm water, and thoroughly draining it before air drying it. Untreated bagasse fibers were used as collected from the sugar cane mill.

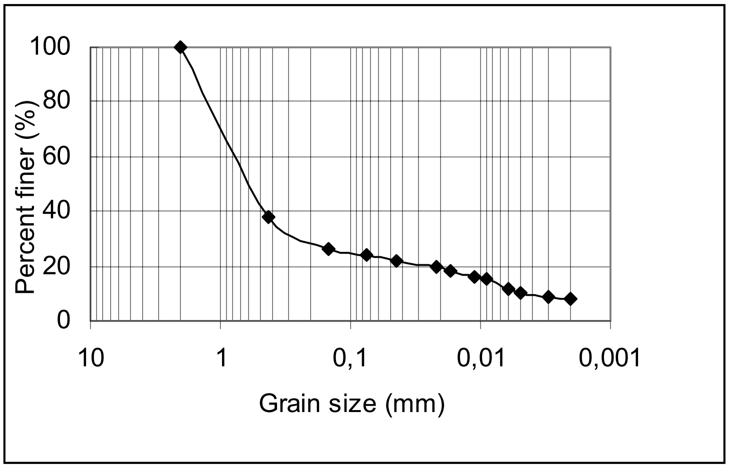

Fig. 1. Grain size distribution of the soil investigated

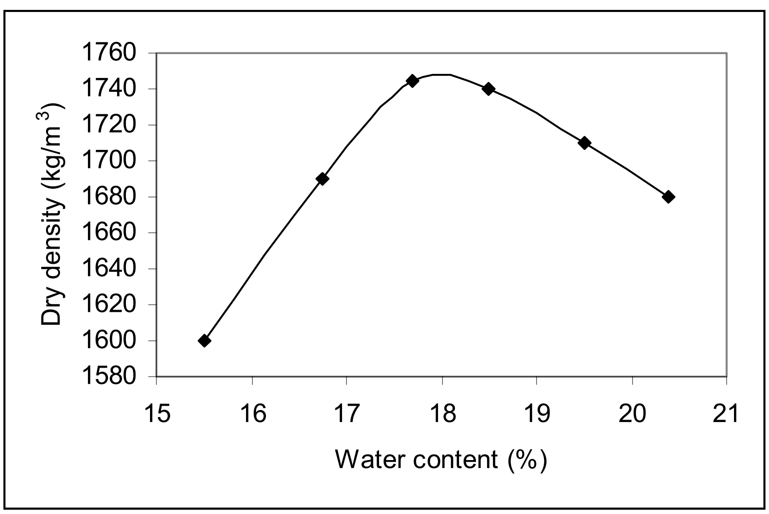

Fig. 2. Dry density -Water content relationship of the soil investigated

EXPERIMENTAL PROGRAM

Maclean and Sherwood (1961) showed that if the organic matter content in soil exceeds 2%, the hydration of cement in soil-cement mixtures cannot proceed. To make sure the plain soil planned to be used did not contain organic matter, a check of organic matter effect on cement hydration was first done. It was done according to the procedure used by Maclean and Sherwood (1961) at Road Research Laboratory, England. It consisted of mixing 150 g of soil, 10% cement by weight, and enough water to form a 500 ml slurry in a beaker, agitating it, and waiting for 15 minutes before making a pH measurement. The pH was found to be 12,06 and it was concluded that the soil did not contain any amount of organic matter which would hamper cement hydration since Maclean and Sherwood (1961) state that organic matter would not hamper the hydration of cement mixed with soil if the pH after 15 minutes is at least 12.

Bagasse was planned to be added to soil-cement mixtures for making soil samples. Appreciable amount of natural fibers was therefore planned to be added to the plain soil. Therefore, the effect of natural fibers on cement hydration needed to be checked. The check was done once again according to the procedure used by Maclean and Sherwood (1961). Two slurries were prepared: the first consisted of 150 g of soil, 10 % cement by soil weight, and 10 % treated bagasse by volume of soil-cement; the second consisted of 150 g of soil, 10 % cement by soil weight, and 10% untreated bagasse by volume of soil-cement. Throughout this investigation, the weight of bagasse fibers was negligible compared to weights of soil and cement. The pH of the slurry with treated bagasse after 15 minutes was found to be 12,01;. it was concluded that treated bagasse fibers would not have any adverse effect on cement hydration. The pH of the slurry with untreated bagasse after 15 minutes was 11,80, which was slightly lower than the requirements set by Maclean and Sherwood (1961). Even for this latter case, it was felt that this pH would not hamper the hydration of cement since pH=11,80 was close to the lower pH limit (pH=12) set by Maclean and Sherwood (1961) for hydration of cement.

Taking a stand based on the test method of Maclean and Sherwood (1961) was unsuccessful because the pH of soil-cement-treated bagasse was not actually different from that of the soil-cement-untreated bagasse; it was therefore decided to use the unconfined compressive strengths of specimens processed each way as a criteria for deciding what scheme to use. Specimens using mixtures processed each way were then made and their unconfined compressive strengths were compared.

In the first step, the compressive strength test of two sets of specimens cured for 7 days in an environmental chamber was carried out. One set consisted of soil, 5 % cement by soil weight, and 10 % untreated bagasse by volume of soil-cement; the other set consisted of soil, 5 % cement by soil weight, and 10 % treated bagasse by volume of soil-cement. The results of this test led us to choose one of the two schemes for processing soil-cement-bagasse samples. The second step aimed at checking the effect of increasing level of cement on the unconfined compressive strength of the samples obtained with the chosen scheme. In this second step, the samples were processed, cured in an environmental chamber for 28 days, then tested for determining their unconfined compressive strength.

<u>Step 1: Comparison between Unconfined Compressive Strength of soil-cement with treated bagasse and Unconfined Compressive Strength of soil-cement with untreated bagasse</u>
To compare the unconfined compressive strength between soil-cement-untreated bagasse and soil-cement-treated bagasse, a procedure similar to that used in lime stabilization to check the reactivity of soil was used. The procedure for checking the reactivity of soil in lime stabilization is described in Transportation Research Board (1987). The one used in this investigation consisted of comparing the compressive strength between specimens processed with silty sand, 5 % cement by soil weight, and 10 % untreated bagasse fibers by volume of soil-cement and specimens made with same silty sand, 5 % cement by soil weight, and 10 % treated bagasse fibers by volume of soil-cement. All the specimens were cured for seven days in an environmental chamber, and subjected to an unconfined compressive strength test according to ASTM D 2166-92 (2000).

<u>Step 2: Unconfined Compressive Strength of soil-cement with untreated bagasse and increasing level of cement</u>
To check the effect of increasing level of cement, specimens were made with various amounts of cement and bagasse, cured for 28 days in an environmental chamber, and subjected to an unconfined compressive strength test according to ASTM D 2166-92 (2000).

MIXING AND PREPARATION OF SPECIMENS

<u>Step 1:</u>
Two sets of three specimens each were done according to the following description. Soil was first air-dried and pulverized. Known weights of soil and cement were then homogeneously and manually mixed with cement. The mixing lasted 10 minutes to ensure an even distribution of cement in the mixture. Volume of dry soil-cement was determined. Then a known proportion of bagasse fibers by volume of soil-cement was mixed with the soil-cement. This mixing was manually done for about 10 minutes to obtain a homogeneous material. Water content up to the optimum moisture content was gradually added to the mix during soil, cement, and bagasse fibers mixing since the mixture was planned to be compacted. The optimum moisture content of a soil is the water content which allows the highest dry density upon compaction of that soil using a given compactive energy. The dry density is the density of a dry soil packed in a given volume. An additional 1 % water beyond the optimum moisture content was then added to allow for the hydration of cement (ACI, 1992). At the end of this process, the computed sugar content in the mix with untreated bagasse was done according to the procedure described in the appendix .

The mix was poured in a steel mold with inner dimensions of 102 x 51 x 43,75 mm and a steel cover was forced into it with a *TINIUS OLSEN* hydraulic press. Each mix was compacted to a known pressure of 1,72 MPa for 10 seconds, then the steel mold was dismantled and the specimen whose dimensions were 102 x 51 x 25 mm was taken out. The level of 1,72 MPa compactive energy was chosen because an investigation on bagasse fibers reinforced concrete by Sera et al. (1990) led to the conclusion that this level of energy was the optimum compactive energy. The specimens were cured in an environmental chamber for 7 days in constant conditions of 25 °C and 91 % relative humidity. It is a procedure commonly used for curing cement based specimens which are then tested for measuring the unconfined compressive strength (Barenberg, 1978).

Step 2:
Nine different fiber reinforced mixtures were used to check the effect of sugar on cement hydration (Table 1). Three specimens identical to those mentioned above were obtained from each of the mixtures prepared as previously described. The mixtures consisted of a predetermined amount of cement by soil weight (5 %, 10 %, or 15 %) and a predetermined amount of fibers by volume of soil-cement (10 %, 20 %, or 30 %). Computed sugar content varied from 3,36 g/l in the mixtures containing 10 % bagasse fibers by volume of soil-cement to 10,08 g/l in the mixtures containing 30 % bagasse fibers by volume of soil-cement (cf. appendix for calculation). They were cured in the environmental chamber at 25 °C and 91 % relative humidity for 28 days after processing.

Table 1. Specifications of the various mixtures used in the investigation

MIX DESIGNATION	MIX COMPOSITION	COMPUTED SUGAR CONTENT (g/l)
C5B10	5% cement by weight and 10 % bagasse by volume	3,36
C5B20	5% cement by weight and 20 % bagasse by volume	6,72
C5B30	5 % cement by weight and 30 % bagasse by volume	10,08
C10B10	10 % cement by weight and 10 % bagasse by volume	3,36
C10B20	10 % cement by weight and 20 % bagasse by volume	6,72
C10B30	10 % cement by weight and 30 % bagasse by volume	10,08
C15B10	15 % cement by weight and 10 % bagasse by volume	3,36
C15B20	15 % cement by weight and 20 % bagasse by volume	6,72
C15B30	15% cement by weight and 30 % bagasse by volume	10,08

RESULTS AND DISCUSSIONS

Step 1:

Specimens with treated bagasse yielded an average compressive strength of 1,03 MPa with a standard deviation of 0,25 MPa. Specimens with untreated bagasse yielded an average compressive strength of 1,72 MPa with a standard deviation of 0,36 MPa. An analysis of variance showed that the two sets were statistically different at the 0,05 level. It was therefore concluded that the best scheme for this investigation was the one with untreated bagasse . The lower unconfined compressive strength observed in mixtures of soil, cement, and treated bagasse fibers stems from the fact that boiling bagasse in water destroyed the lignin long carbon chains. As a result, the bagasse fibers were weaker, which reduced the unconfined compressive strength of specimens with treated bagasse fibers.

Sugar content in mixtures with untreated bagasse was higher than the critical sugar content (0,5 g/l) mentioned by Mindess and Young (1981), but this did not hamper cement hydration. Sugar content failed to hamper strength gain due to the fact that during the long storage which lasted seven months in the room environment (22 °C and 60-70 % relative humidity), bagasse sugar supposedly evolved to the form of polysaccharides. Polysaccharides in soil are known to act as binding agents since they aggregate clay particles (Greenland, 1965; Theng, 1982).

Step2:

The average unconfined compressive strength increased with the increasing level of cement (Figure 3). The effect of Portland cement in this case was similar to the effect of Portland cement in soil-cement mixtures (ACI, 1992). When mixed with soil containing a certain amount of water, cement releases Ca^{++} ions in the medium (Mindess and Young, 1981). These ions are particularly attracted to negative sites provided by clay minerals as well (Marshall and Holmes, 1992). As Ca^{++} ions cling to these negative sites, they draw neighboring clay particles together. As a result, a damped soil containing cement ends up being a medium where chemical compounds act for binding clay particles. The main source of observed strength in this material is due to $C_3S_2H_3$ compounds formed through the connection of Ca^{++} and Si^{3+} in water. When soil and cement are mixed in water, the high pH brought about by cement destroy clay minerals which release Si^{3+}. Ca^{++} ions released by cement then connect to the Si^{3+} ions from clay minerals to form C_3S and C_2S compounds. Since this occurs in water, these former compounds hydrate to form $C_3S_2H_3$ compounds. The latter compounds are the well known binding agents, responsible for the strength observed in soil-cement-bagasse mixtures as well as in concrete (Mindess and Young, 1981).

Data from tests carried out for determination of compressive strength were used to check the effect of increasing level of bagasse above 10% on compressive strength of soil-cement-bagasse mixtures. Increasing level of bagasse fibers above 10% actually decreased the compressive strength (figure 4). The decrease of strength with increasing level of bagasse fibers was connected to the volume change of materials which occurred in the mixture. At the early stage of material processing, bagasse fibers, soil, and cement were mixed with water. This water favored their volume increase. Upon drying, they shrunk and stress concentrations occurred at the fiber and soil-cement interface. These stress concentrations in turn led to microfractures at the same locations. As the fiber content increased, the amount of microfractures increased and the strength of the material decreased (figure 4). The binding action of polysaccharides mentioned above should have favored the specimens strength increase resulting from am increase of untreated bagasse fibers in various mixtures. The effect of increasing level of bagasse fibers rather shows that the polysaccharides action was actually negligible in providing strength observed in soil-cement-untreated bagasse mixtures.

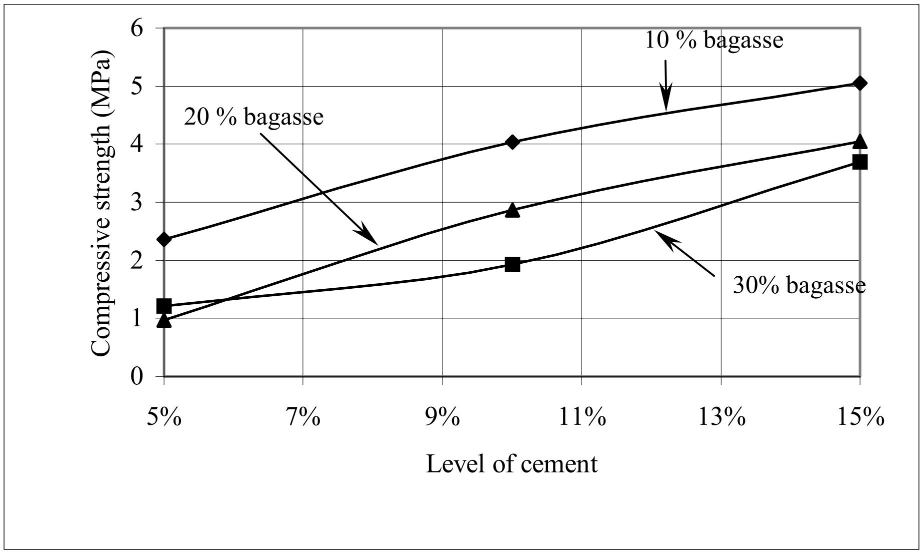

Fig. 3. Effect of increasing level of Portland cement on the unconfined compressive strength

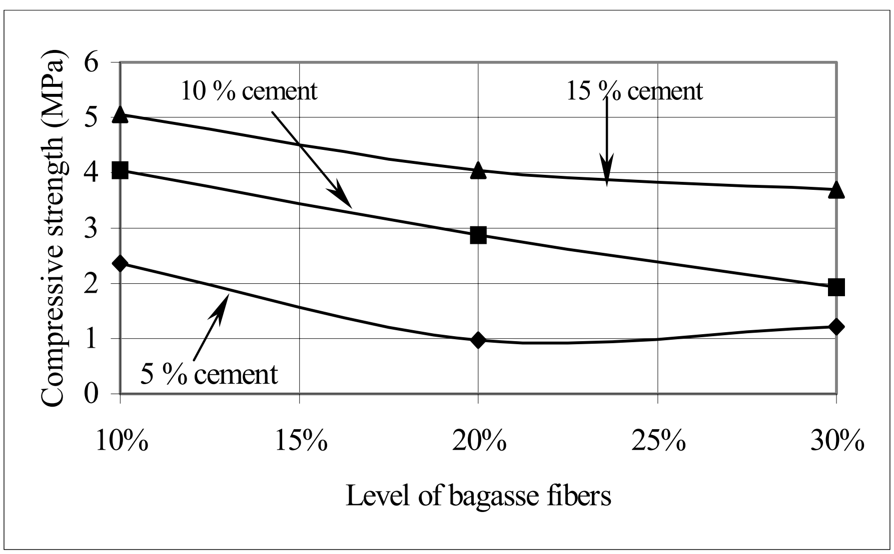

Fig. 4. Effect of increasing level of bagasse fibers on the unconfined compressive strength

CONCLUSIONS

The tests carried out here show that it is not necessary to remove sugar from sugar cane bagasse when plans are made to use it as reinforcement in soil-cement. This paper shows that although the sugar content in soil-cement-untreated bagasse is higher than the critical value which hampers cement hydration in cement-based materials, unconfined compressive strength of specimens made out of these mixtures increases with increasing level of cement (figure 3). The methodology used here, which consists of first checking effects of organic matter and natural fibers on cement hydration while planning to handle mixtures of soil, cement, and a natural fiber presumed to contain a certain amount of sugar turned out to be efficient in guiding the investigators to the best scheme to use for meeting the goal of the investigation. Mixing untreated bagasse fibers with soil-cement can therefore be recommended as an efficient procedure for processing house construction bricks in rural Africa when this building material is made out of soil, cement, and bagasse fibers: it is less time consuming, less energy intensive, and more economical since water is not needed for treating bagasse fibers before they are used . Although this research finding is intended for rural African population, it may be used elsewhere in the world where sugar cane is grown and house construction bricks are made out of materials listed in this paper.

REFERENCES

1. ACI. 1992. *The State-of-Art Report on Soil-Cement*, American Concrete Institute, Detroit, MI**.**

2. ASTM. 2000. Test method for particle size analysis of soils, ASTM D 422-63, American Society for Testing and Materials, Philadelphia, PA. Vol 04.08.

3. ASTM. 2000. Test method for laboratory compaction characteristics of soil using standard effort (600 kN.m/m^3), ASTM D 698-91, American Society for Testing and Materials, Philadelphia, PA, Vol 04.08

4. ASTM. 2000. Test method for unconfined compressive strength of cohesive soil, ASTM D 2166-00, American Society for Testing and Materials, Philadelphia, PA, Vol. 04-08.

5. ASTM. 2000. Test method for liquid limit, plastic limit, and plasticity index of soils, ASTM D 4318-95a, American Society for testing and Materials, Philadelphia, PA, Vol 04.08

6. Barenberg, E. J. 1978. Lime or lime and cement-fly ash- aggregate mixtures for use in pavement construction, *Proceedings of Conference on Ash Technology and Marketing*, London, England.

7. Greenland, D.J. 1965. Interaction between clays and organic compounds in soils: Part 2, adsorption of soil organic compound and its effect on soil properties, *Soils and Fertilization*, Vol.28, pp. 521-532.

8. Lock, A. 1969. *Practical Canning*, 3rd edition, Food Trade Press, London, England.

9. Maclean, D.J. and P.T. Sherwood . 1961. Study of the occurrence and effects of organic matter in relation to the stabilization of soils with cement, *Proceedings Fifth International Conference on Soil Mechanics and Foundation Engineering*, England, U.K..

10. Marshall, T.J. and J.W. Holmes. 1992. *Soil Physics*, Cambridge University Press, Melbourne, Australia.

11. Medjo Eko, R. and G. L. Riskowski. 1994. Effects of fibers and cement on the mechanical behavior of soil-cement reinforced with sugar cane bagasse, *Int. J. Housing Sc*., Vol. 18, No 2, pp. 79-89.

12. Mindess, S. and F. Young. 1981. *Concrete*, Prentice Hall Inc., Englewood Cliffs, New Jersey

13. Sera, E.E., L. Austriaco-Robles, and R.P Pama. 1990. Natural fibers as reinforcements, *Journal of Ferrocement*, Vol. 20, pp. 36-40.

14. Shokry, M.R, M. Hatzinikolas, and R. Zmave. 1992. Development of a lightweight, low cost concrete block using wood residue, *Forest Products Journal*, Vol. 42, No. 5, pp.

15. Theng, B.K.G. 1982. Clay-polymer interactions: summary and perspectives, *Clays and Clay Min.*, Vol.30, pp 1-10. .

16. TRB. 1987. *Lime Stabilization*, Transportation Research Board, National Research Council, Washington, D.C.

APPENDIX: PROCEDURE FOR COMPUTING THE SUGAR CONTENT IN SOIL-CEMENT-BAGASSE MIXTURES

1. To determine the volume of sugar juice used in mixtures containing 10% bagasse volume (step 1 of experimental program), sugar juice droplets from untreated bagasse fibers were squeezed onto the translucent glass of an *ATAGO N1 (0-32 degree Brix)* hand held refractometer; the volume of this sugar juice was measured and was found to be 5 ml.
2. To determine sugar content in mixtures using 10% bagasse fibers, a test with the hand held refractometer yielded 14 degree brix; computation of the corresponding sugar content using tables by Lock (1969) yielded 153 g/l.
3. To determine sugar content in mixtures of soil-cement and 10% bagasse by volume, the following equation was used:

$$N_1 V_1 = N_2 V_2 \qquad (1)$$

where:

N_1 = concentration of sugar in syrup prior to mixing (g/l) = 153 g/l
V_1 = volume of syrup prior to mixing (ml) = 5 ml
N_2 = concentration of sugar in the mixture of soil-cement-bagasse after mixing (g/l)
V_2 = volume of soil-cement-bagasse after mixing (ml)

Determination of V_2 was done using inner dimensions of the mold used for making specimens (102 x 51 x 43,75 mm). Using the equation (1) therefore yields a N_2 concentration equal to

3,36 g/l after mixing. Twenty per cent and 30% bagasse content by volume of soil-cement correspond, respectively, to 7,72 and 10,08 g/l (Table 1) in this context.