Mechanical Behaviour of Sisal Fibre Reinforced Cement Composites

M. Aruna

Abstract**—**Emphasis on the advancement of new materials and technology has been there for the past few decades. The global development towards using cheap and durable materials from renewable resources contributes to sustainable development. An experimental investigation of mechanical behaviour of sisal fibre-reinforced concrete is reported for making a suitable building material in terms of reinforcement. Fibre reinforced Composite is one such material, which has reformed the concept of high strength. Sisal fibres are abundantly available in the hot areas. Sisal fibre has emerged as a reinforcing material for concretes, used in civil structures. In this work, properties such as hardness and tensile strength of sisal fibre reinforced cement composites with 6, 12, 18 and 24% by weight of sisal fibres were assessed. Sisal fibre reinforced cement composite slabs with long sisal fibres were manufactured using a cast hand lay up technique. Mechanical response was measured under tension. The high energy absorption capacity of the developed composite system was reflected in high toughness values under tension respectively.

Keywords**—**Sisal fibre, fibre-reinforced concrete, mechanical behaviour.

I. Introduction

NATURAL fibres are now considered as a suitable reinforcing material in concrete, due to their greater advantages, which include low cost, high strength-to-weight ratio, and recyclability. The benefit of composite materials over conventional materials seams largely from their higher specific strength, stiffness and fatigue characteristics, which enable structural design to be more versatile. Natural fibres are expected to be the reinforcing materials and their use until now has been more traditional than technical. They have long served many functional purposes but the application of materials technology for the consumption of natural fibres as the reinforcement in concrete has only taken place in comparatively current years. Sisal fibre is obtained from the leaves of the plant *Agave sisalana*, which was originated from Mexico and is now mainly cultivated in East Africa, Brazil, Haiti, India and Indonesia. The name "sisal" comes from a harbour town in Yucatan, Maya, Mexico [1]-[2]. It is grouped under the broad heading of the "hard fibres" among which sisal is placed second to manila in durability and strength [3].

Fibres have been used to toughen bricks and pottery since the very beginning of civilization, but only in the last twenty five years have the principles of fibre reinforcement of brittle matrices began to be scientifically implicit. In recent years, a great transaction of notice has been created world wide on the potential applications of natural fibre reinforced, cement based composites. Investigations have been carried out in many countries on various mechanical properties, physical performance and durability of cement based matrices reinforced with naturally occurring fibres including sisal, coconut, jute, bamboo and wood fibres. These fibres have always been considered promising as reinforcement of cement based matrices because of their availability, low cost and low consumption of energy [4]. A sequential progress of sisal fibre reinforced, cement based matrices is reported and experimental data are provided to illustrate the performance of sisal fibre reinforced cement composites.

Studies of sisal fibre reinforced concrete were started in Sweden in 1971 by Nilsson [1]. Cut fibres with a length of 10-30mm were cast into beams and an improvement in the tensile strength in bending was observed for fibre reinforced specimens. It was found that toughness increased markedly when continuous fibre was used. In 1977 the Building Research Unit (BRU) in Dar es Salaam started collaboration on the development of roof sheets on natural fibre reinforced concrete with the Swedish Cement and Concrete Research Institute [5]-[9]. Test sheets were manufactured for durability experiments. A special roof sheet profile was developed and several buildings in Dar es Salaam have been provided with sisal fibre reinforced concrete roofs. The use of sisal fibre as reinforcement in cement paste and concrete has been reported by Swift and Smith [10], [11]. Their results on the flexural static strength and toughness of beams made of cement based matrices reinforced indicated that extremely high strengths can be achieved using suitable mixing and casting techniques with optimum fibre volume fraction, although the modulus of rupture is found for different ages. They also found that impact resistance can be enhanced by the addition of sisal fibres. Several application of this material was suggested for low-cost housing and they produced corrugated sheets in different ways to optimize the processing technique.

In general, a relatively low content fibre results in small positive influence on the concrete. A relatively high content of fibre, however, may have a difficulty in mixing and distribution of fibre [12].

II. Experimental Procedure

A. Materials and Processing

The necessity for reasonable, sustainable, harmless, and secure shelter is an inherent global problem and several challenges remain in order to produce environmentally friendly construction products which are structurally safe and durable. The use of sisal, a natural fibre with enhanced

Dr. M. Aruna is with the Mechanical Engineering Department, Velammal College of Engineering and Technology, Madurai, 625 009, Tamil Nadu, India (e-mail: mar@vcet.ac.in).

mechanical performance, as reinforcement in a cement based matrix has shown to be a promising opening. This work addresses the development and advances of hardening cement composites using sisal fibre as reinforcement. Sisal fibres were used as a fabric to reinforce a multi-layer cementitious composite with a low content of Portland cement. Monotonic direct tensile tests were performed in the composites. Continuous sisal fibres were obtained. Mechanical properties of bulk fibres defined in terms of Young's modulus and tensile strength of 19 GPa and 400 MPa, respectively were reported by Silva et al. [12]. The sisal fibres are extracted from the plant leaf which is a functionally graded composite structure reinforced by three types of fibres: structural, arch, and xylem fibres [12]. The structural fibres are located in the periphery of the leaf providing resistance to tensile loads. The arch and xylem fibres are located in the middle of the leaf and present secondary reinforcement as well as a path for nutrients. These fibres present different geometries which may result in different fibre–matrix bond strengths. After receiving the sisal fibres they were washed, cut to long sections, weighed and separated into four different layers in order to result in a total volume fraction of 10%. Table I detailed the physical properties of sisal fibres. Fig. 1 represents the fresh sisal leaf.

TABLE I
PHYSICAL PROPERTIES OF SISAL FIBRES

Fibre type	Sisal
Fibre length (mm)	180-160
Fibre diameter (mm)	0.1-0.5
Tensile strength(N/mm^2)	31-221
Elongation (%)	14.8
Specific gravity	1.4
Elastic-modulus (GPa)	7.83

Fig. 1 Fresh Sisal leaf

Fig. 2 Hand lay up concrete slab with sisal fibre

Fig. 3 Sisal fibre-reinforced 4 Concrete slabs

The experimental work involved extensive laboratory testing to study the influence of volume fraction, fibre length, fibre arrangement and matrix composition on the mechanical properties of the composite. The workability of the fresh mix was shown to be closely related to the volume fraction and fibre aspect ratio. An increase in fibre volume fraction and fibre length reduced the workability of the mix. It was established that, for volume fractions smaller than 3% and fibre length smaller than 50mm, the mixes could be manually compacted or vibrated without balling. Fig. 2 displays the Hand lay up concrete slab with sisal fibres. Fig. 3 shows the concrete slabs reinforced with various % of sisal fibres. The matrix was produced using the Portland cement. The mortar matrix used in this study presented a mix design 1:1:0.4 (cementitious material: sand: water by weight). The used river sand presented a maximum diameter of 1.18mm and density of $2.67g/cm^3$. All test specimens were prepared with a geometry of 400mm×50mm×12mm. (length×width×thickness) and reinforced by 10% of 400mm sisal fibres distributed in layers. The final composite layered structure presented 3 layers of fibres (∼1.2mm each) and 6 matrix layers (∼1.0mm each). After casting, composites were compressed for 24 hours, followed by curing in the mold for 24 hours. After de-molding, samples were fog-cured for 30 days in a curing chamber with 100% RH and 23±1◦C. Since it was planned to study the behaviour of all the mixes after 30 days, totally 4 specimens each for every test were cast. The water–cement ratio used was 0·5. The fibre content was restricted to 1·5% volume fraction of concrete volume. Similarly aspect ratio of 60 was considered for both the fibres. The fibre reinforced concrete specimens were allowed for initial curing of 30 days. After 30 days curing, the specimens were allowed to dry in open air for 4 days.

B. Mechanical Testing

Mechanical strength tests were carried out on the 4 concrete slabs at room temperature and as per the Indian standards. Direct tensile tests were performed in an Instron universal testing machine with a capacity of 500 kN. The tests were controlled by the cross-head displacement at a rate of 0.1 mm/min. A chronological development of sisal fibre reinforced, cement based matrices is reported and experimental data are provided (Table II) to illustrate the performance of sisal fibre reinforced cement composites. In cement based composites the two major roles played by the fibres are to improve the toughness and the post-cracking performance of the matrices. Also some changes were created to the pre-cracking behaviour of the hardened matrix, which help to define the composite action. Addition of sisal fibres to cement mortar matrices reduced the compressive strength by 21.36 from 23.71%.

TABLE II
COMPRESSIVE STRENGTHS OF CEMENT MORTAR COMPOSITE SLABS (1:3, CONSTANT FLOW)

Sl.no	Sisal fiber content (%)	Sisal
1.	0	23.71
2.	1	21.36
3.	2	19.76
4.	3	20.62

Fig. 4 Sisal fibre reinforced tested slabs (1% fibre)

Fig. 5 Sisal fibre reinforced tested slab (3% fibre)

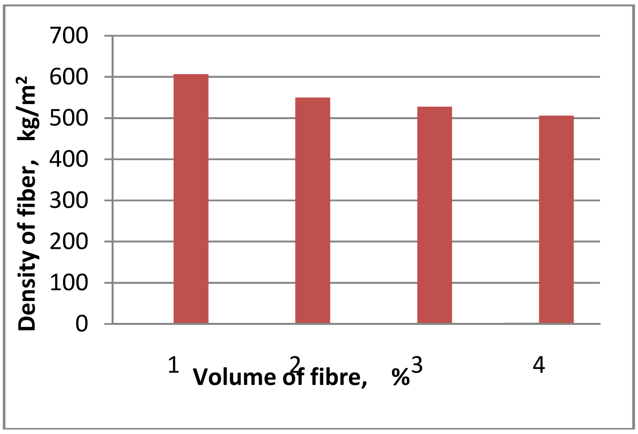

Fig. 6 Volume Vs Density of fibre plot

Figs. 4 and 5 clearly depicts the sisal fibre reinforced tested slabs with 1% fibre and 3% fibre cement composite slabs. The mode of failure and the properties of the resistance to fibre-matrix interfacial bonding were determined using the single fibre pull-out test. Both fibre fracture and fibre pull-out were found to occur in sisal fibre reinforced mortar composites. Specimens with short embedment length tended to pull out whereas those with long embedment length tended to fail in tension. As most of the systems with fibre embedment length greater or equal to 25mm failed by fibre fracture, this length can be suggested as a critical length for sisal fibres.

Fig. 6 shows the variation of volume of sisal fibre, against density of sisal fibre. From the figure it is observed that, all the three mixes reveal a slight decrease in density over the volume of sisal fibre. Among all the mixes concrete mix possesses the highest density. The conventional concrete specimen shows a compressive strength of 23·71 N/mm^2 at 30 days curing. The sisal fibrous concrete specimens show their compressive strength as 21·36, 19.76 and 20·62 N/mm^2, respectively with 1, 2, 3 % sisal fibre content.

III. CONCLUSION

The understanding of sustainability in building construction has also undergone changes over the years. First attention was given to the issue of limited resources, especially energy, and how to reduce the impact on the natural environment. Now, emphasis is placed on more technical issues such as materials, building components, construction technologies and energy related design concepts as well on non-technical issues such as economic and social sustainability. Use of continuous sisal fabrics that are formed by aligning and stitching the fibres in a multilayer cement composite system present a new perspective for the use of natural fibre reinforced composites in the construction industry. Many investigations are being carried out to establish the durability of sisal reinforcement. The results show that the composites reinforced with sisal fibres are reliable materials to be used in practice for the production of structural elements to be used in rural and civil construction. This material could be a substitute asbestos-cement composite, which is a serious hazard to human and animal health and is prohibited in industrialized countries. The production of sisal fibres as compared with synthetic fibres or even with mineral asbestos fibres needs much less energy in addition to the ecological, social and economical benefits.

REFERENCES

[1] M. RaNilsson, L. 1975: “Reinforcement of concrete with sisal and other vegetable fibres”, Stockholm: Swedish council for building research, Number 4, 68 pp.
[2] Mattoso, L. H. C., F. C.Ferreira, A. A. S.Curvelo, 1997: “Sisal fiber: Morphology and applications in polymer composites”, Lignocellulosic-plastics composites - sãopaulo: usp/unesp, 21-51.
[3] Romildo Dias Toledo Filho, Kuruvilla Joseph, Khosrow Ghavami and George Leslie England, 1999: “The use of sisal fibre as reinforcement in cement based composites”. Revistabrasileira de engenhariaagrícola e ambiental. Volume3, Number 2, 253–256.
[4] Cappelen, P. 1978: “Roof sheets made of sisal reinforced concrete”. Building Research Unit, Ministry of Lands Housing and Urban Development. Working Report, WR 14, 1-7.

[5] Bru Data Sheet, 1978: "Roof sheets made of sisal reinforced concrete". Dar es Salaam: Building Research Unit, 1-8.
[6] Mwamila, B.L.M., 1979: "Flexural behaviour of concrete elements reinforced with sisal fibres". Dar es Salaam: University of Dar es Salaam, 185pp.
[7] Mwamila, B.L.M., 1987: "Characteristics of natural fibrous reinforcement in cement-based matrices". Symposium on building materials for low income housing, Bangkok, Thailand, Jan. 20-26, 87-93.
[8] Mawenya, A.S.; Mwamila, B.L.M., 1979: "Characteristics of sisal as a reinforcing fibre". Faculty of Engineering, University of Dar es Salaam, 1-22pp.
[9] Swift, D.G., R. S.L. Smith, 1978: "Sisal fibre reinforcement of cement paste and concrete". In: Materials of construction for developing countries, Angkok, 221-233.
[10] Swift, D. G., R.S.L. Smith, 1979: "Sisal-cement composites as low cost construction materials". Appropriate Technology, London, Volume6, Number 3, 6-8.
[11] Silva, F.A., N. Chawla, R.D. Toledo Filho, 2008: "Tensile behavior of high performance natural (Sisal) fibers", Comp. Sci. Technol. Volume 68, 3438–3443.
[12] Choi, Y., Yuan, R.L, 2005: Experimental relationship between splitting tensile strength and compressive strength of GFRC and PFRC. Cement & Concrete Research 35(4), 1587–1591.

Dr. M. Aruna received her B.E in Mechanical Engineering from Bharathiyar University and M.E in Industrial Engineering from Madurai Kamaraj University. She received her PhD from Anna University- Chennai, India. Currently, she is a Professor in the department of Mechanical Engineering at Velammal College of Engineering and Technology, Madurai, India. She has published 12 papers in International Journals, 2 papers in National Journal and 10 papers in various International and National Conferences. Her research interests include Metal Machining, Optimization, Composites, Industrial and Business management.