TITLE PAGE

THE USE OF RICE STRAW IN THE PRODUCTION OF COMPRESSED STRAW SLABS.

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE. M.Sc. IN CONSTRUCTION TECHNOLOGY.

MARCH, 1999

DECLARATION

I solemnly declare that this research work has been carried out wholly by me and that no similar work is seen any where in the literatures.

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(M. Sc. Construction Technology).

CERTIFICATION

This thesis entitled, "The use of rice straw in the production of compressed straw slabs" by Apeh Abah Joseph meets the regulations governing the award of the Degree of Master of Science (M.Sc.) in Construction Technology, Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This thesis is dedicated to:

The Almighty God

and

My son, Mike C. O. Apeh.

ACKNOWLEDGEMENT

I wish to express my profound and sincere gratitude to my lecturer and Chairman of my supervisory committee, Dr. O. G. Okoli of the Department of Building, Ahmadu Bello University, Zaria, for his expert advice and able supervision during the course of this research. I do also extend my heart felt gratitude to all members of the supervisory committee especially Mallam M. M. Garba, Zubairu I. K., Kabiru Bala and the entire staff of the Department of Building.

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My thanks also goes to my close relations, my family, brothers and sisters especially my senior brother, Mr Paul A. Apeh who rendered moral and financial assistance during the course of my study. He has played a very vital role in my academic pursuit. May God reward him abundantly in Jesus' name. Amen.

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This acknowledgement will be incomplete if I fail to thank the Almighty God who has been my Pilot and still my Captain in all my endeavours. Thank You Jesus.

ABSTRACT

The properties of compressed straw slabs were investigated. The aim of the study is to determine the physical and mechanical properties of the compressed straw slabs (CSS) produced using rice straw. The study consists of extensive literature review of available relevant literature and laboratory tests. After review of literature which served as background knowledge, the compressed straw slabs were produced using two types of binders namely. Gum Arabic and Cement identified as CSS-1 and CSS-2 and using a constant mix ratio of 30% straw and 70% binder. An adapted version of a screw pressing machine was used for pressing the slabs with a maximum capacity of 0.1344N/mm^2. The properties of CSS-1 and CSS-2 considered in the study were density, moisture content (physical properties) and the mechanical properties considered were conductivity and bending strength (modulus of rupture). After curing for 30 days, the slabs were tested for the aforementioned properties.

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It was found that CSS-1 has an average density of 303.2Kg/m^3. a moisture content of 8.70%, a conductivity of 0.035w/m°C and a bending strength of 0.33N/mm^2. On the other hand. CSS-2 has *an* average density of 425.53Kg/m^3. a moisture content of 5.26%. a conductivity of 0.025w/m°C and a bending strength of 0.29N/mm^2.

These values conform to those in existing standards (BS 4046, Parts I & II. 1966 and 1971, BS 1142, Part I, 1971, BS 1811, Part I, 1971 and F.A.O Standards for Plywood and other Wood Based Panels: 1963). In this light, both types of slabs are recommended (after further investigation) for use as insulating material, and for permanent formwork for reinforced concrete elements.

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LIST OF SYMBOLS, ABBREVIATIONS & CODES

SYMBOLS

1.	ρ (Rho)		Density kg/m^3 or g/mm^3.
2.	l	-	Length of specimen, L - overall length of specimen.
3.	b	-	Breadth/width of specimen.
4.	t	-	Thickness of specimen (mm); time in (secs).
5.	v	-	Volume (mm^3) or M^3.
6.	kg	-	Kilogram.
7.	g	-	Grams.
8.	n	-	Newtons.
9.	kn	-	Kilo Newtons.
10.	s	-	Bending Strength (Modulus of Rupture).
11.	p	-	Load.
12.	d	-	Diameter.
13.	K	-	Degree Kelvin.
14.	°C	-	Degree Celsius.
15.	M^c	-	Moisture Content.
16.	λ	-	Thermal conductivity (Lambda).
17.	c	-	Specific heat capacity of substance.
18.	w	-	Watts.
19.	A	-	Area MM^2, M^2.
20.	M	-	Metre, Main of straw, or other substance.
21.	MM	-	Millimetre.
22.	Q	-	Quantity of heat flow between two surfaces.
23.	T	-	Temperature.
24.	dΘ	-	Change in Temperature.
25.	dt	-	Change in Time (sec).
26.	%	-	Percentage
27.	dΘ/dt	-	Rate of Cooling in fall of Temperature with respect to time.
28.	Po	-	Minimum force required to raise pressing pad.
29.	F	-	Total load required to compress slab per pitch of the screw.
30.	Θ	-	Angle the pitch of the screw makes with the horizontal.
31.	Φ	-	Angle of friction.
32.	μ	-	Coefficient of friction, Micron. (10-6)

LIST OF ABBREVIATION

1.	BS	-	British Standard.
2.	BSI	-	British Standard Institute.
3.	FAO	-	Food and Agriculture Organisation.
4.	UN	-	United Nations.
5.	UNIDO-		United Nations Industrial development Organisation
6.	IRRI -		International Rice research Institute.
7.	USA	-	United States of America.
8.	∴	-	Therefore
9.	i.e.	-	That is;

LIST OF CODES AND STANDARDS

1. Bs 4046 Part I & II - Specification of compressed straw Building slabs. 1969 and 1971.
2. Bs 1142 Part I: 1971 - Specification for fibre building boards.
3. Bs 1811: Part II: 1969 - Methods of test for wood chip boards and other particle boards.
4. Bs 476: Part V: Test for Ignitability of materials.
5. F.A.O.S. : 1963 - Food and Agriculture Organisation Specifications obtained from "Plywood and other wood - based panels.

CHAPTER ONE

1 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

After air, water and food, (the three necessities of life) the next important thing to man is shelter. In providing shelter for himself, man has used many type of construction materials among which concrete is the most widely used in modern building or civil engineering structures. Developments and advancement in these materials implies that one has to work within societal constraints e.g. economy flexibility and inability to make use of locally available materials that will reduce costs and still advance the level of indigenous technology.

New researches into the use of materials especially locally available waste materials and by-products becomes necessary as a result of scarcity and high cost of construction materials such as cement. Studies on fly-ash (finely divided residue from combustion of ground coal); Rice-Hull ash, RHA (obtained by burning rice Hulls) have been carried out as partial substitution for cement.

Other studies on maize cobbs, groundnut shells, Bagasse (a major by-product of sugar production); and cereal straws such as Rice straw have been carried out in the production of particle boards. Oguntuase (1977) have shown that groundnut shells is a suitable materials in the production of particle board and Zubairu (1989) has also shown that maize cobbs is a suitable materials for particle board production. Nnabuife and Bryant (1989) have also shown that agricultural wastes such as Bagasse, coconut husk, rice

straw, groundnut shell, and elephant grass are suitable for particle board production.

Unido 1972 report reveals that Agricultural wastes such as rice straw has been lately used in the production of compressed straw slabs under various trade marks.

las-Anders Hermansson (1993), produced compressed straw slab using wheat straw and cement as a binding agent. However, none of these researches has been able to establish a simple means of production. the physical and mechanical properties of the compressed straw slab.

1.2 AIMS AND OBJECTIVES

The aim of this research is to determine the suitability of rice straw in the production of compressed straw building slabs for use in Low Cost Building Constructions.

To realise this goal, the following objectives will be pursued:

1. To establish the production processes and concepts of "compressed straw" building slabs.

2. To produce samples of compressed straw slabs using rice straw in the laboratory. Evaluate some engineering properties (physical and mechanical properties) namely density and bending strength of samples of slabs produced via tests such as modulus of rupture (bending strength) test, thermal

conductivity test, Density and Moisture content tests e.t.c in the laboratory.

3. To Compare results obtained from tests with specifications in the existing standards and hence find out if the slabs is suitable for use for low cost constructions.
4. To propose ways or methods of application.

1.3 SCOPE AND LIMITATIONS

The study is limited to determining the suitability of rice straw for the production of compressed straw slabs. It is also limited to laboratory tests. The performance of the slabs in building is beyond the scope of this study.

1.4 RESEARCH METHODOLOGY

Relevant literature on the subject matter were reviewed. The research was then carried out by means of laboratory tests. The compressed straw slabs were produced using two binding agents namely Gum Arabic and cement. The straw slabs produced using Gum Arabic was identified as CSS 1 while that produced using cement was marked as CSS 2. The binder Gum Arabic is readily available, relatively low in cost locally produced and exported. A resin concentration level of 70% was found suitable and adopted after trials.

The straw was soaked for two days in a 5% by weight solution of sodium chloride and then air dried to surface dryness and then weighed. A quantity of the binder was weighed too and both mixed

to form a mix or paste in a 470 mm x 310 mm mould.

The mix in the mould was gently lifted into the local press on a thin steel plate (2mm) was placed on top of the mix in the mould. The screw press was operated and a pressure of 0.02N/mm^2 was applied for a duration of 72 hours.

The slab was then gently removed from the local press, stripped, trimmed and then cured by simply keeping it at room temperature in a well ventilated area for 30 days before testing. Similar slabs (36Nos) were then produced.

The slabs were then sawn into test specimens (144) and tests to determine the physical and mechanical properties were conducted.

These include: Density, Bending strength (modulus of rupture), moisture content and thermal conductivity.

The tests were conducted in accordance with the British Standards (BS 4046, Part I and II, 1966 and 1971), BS 1142: Part I: 1971, 1811: Part I, 1971 and F.A.O.S: 1963).

The results of the investigations were compared with the aforementioned standards and conclusions drawn and recommendations made.

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CHAPTER TWO
2 LITERATURE REVIEW

2.1 SLABS - GENERAL

To facilitate the appraisal of the properties and quality of compressed straw building slabs produced from Rice Straw. it is imperative to review the characteristics of closely related products.

A slab is a structural element whose dimensions in plan is far greater than its thickness. It is generally classified into two main groups - Reinforced concrete slabs and unreinforced slabs or slabs made from a material. The reinforced concrete slab is made from concrete reinforced with steel bars. In most cases, it is rectangular in plan but other shapes occur in practice such as oval, circular or trapezoidal. Depending on functionality, slabs could be classified as simply supported, continuous, cantilevered, solid, hollow, flat and ribbed.

It is designed on the assumption that it consists of strips of beams monolithicallly casted. It is used in floors, roofs, and walls of buildings and as the decks of Bridges.

UNREINFORCED SLABS - This type of slab normally derives its name from the material from which it is made. It is, unlike reinforced concrete slab a non-structural, flexural element. This type of slab is mainly used for partitions, ceiling/wall boards and as formworks. Examples are woodwool slabs, cement-bonded straw slabs, Rice husk slabs, clay-bonded straw slabs and stramit e.t.c.

It should be noted that these unreinforced slabs are mainly made from woodwool and materials derived from agricultural wastes.

2.2 COMPRESSED STRAW BUILDING SLABS.

Compressed straw building slabs production started from the late 1800s when well pressed Bales of straw weighing about 40kg and half a meter in width were plunged into a cement slurry and built up on a concrete foundation. (Bainbridge et al. 1989).

2.2.1 DEFINITION

BS 4046:1971 defined compressed straw building slabs which are known by the trade name "Stramit: as "straw compacted only by heat and pressure, surfaced with, and bound at the edges with paper and with or without an added bonding agent, consolidated by heat and pressure within a smooth lining". It has a density of 365 kg/m3, thermal conductivity (K) of 0.101 w/moC and spread of flame of class 3 (BS 476) and thickness between 49mm and 53 mm. Principally, it is used for partitions, as light thermal insulating boards (ceiling boards), roof decking and permanent shuttering to concrete walls.

At present, it is made principally from agricultural waste such as straws, woodwool, rice husks. Further works on its production from elephant grass, Bagasse are underway (Journal of the Network of African countries on local building materials and Technologies, April 1, 1989).

2.2.2. BASIC PROCESSES IN THE MANUFACTURE OF COMPRESSED STRAW BUILDING SLABS

The manufacture of compressed straw building slabs starts with cleaning the basic material - straw. This is then soaked for two days in a 5% calcium chloride (CaCl2) solution and then dried to its equilibrium moisture content (10%) according to Hermansson. (1993). The straw and the binder are then weighed according to certain proportions by weight. For example, 70% straw to 30% binder or 72% straw to 28% binder among others.

Both materials are then thoroughly blended and fed into moulds. Care is taken such that it is packed well and pushed with a trowel along the sides and corners of the mould. The mix is then compressed with the trowel and spread evenly over the whole surface of the mould. It is then gently lowered into the pressing machine and then pressed for a period and left to harden.

After hardening, it is removed from the machine and then gently stripped from the mould. The edges are trimmed and it is cured for seven days, few weeks or months depending on the size of the slab. After curing, it is then ready for use.

2.2.3 ORIGIN AND DEVELOPMENT OF COMPRESSED STRAW BUILDING SLAB PLANTS

The use of straw slabs as thermal insulating material and plaster base in walls started in Europe at the beginning if this century. These slabs consisted of compressed straw bound by

galvanised wire and impregnated against rot; however, the slabs ceased to be used as building material in Sweden during 1960 - 1965 and were replaced by other materials.(Hermansson, 1993). Since they were replaced by other materials, machinery for their production on commercial basis could not be developed and established.

After the second world war, the use of straw as a building material was revived on a large scale in West Germany. This was necessary in order to reconstruct 100,000 dwellings in the rural areas, where there was no cement or coal for brick making (Ekblom, 1990). These developments continued and became more prevalent in developing countries whose economy is based mainly on agriculture. With agro-industrialisation during the past three decades, many of these developing countries find themselves with a growing surplus of agricultural wastes e.g. rice hull, rice straw, groundnut shell, bagasse among others presenting serious problems of disposal.

Research on and development of several of them have progressed to the point where the establishment of industrial plants using them for the production of building materials is being seriously considered. (U.N.Publications, New York, 1976). Examples are: Preliminary investigation carried out at the Central Building Research Institute at Roorkee, India, have shown that coconut husk and corn fibre combined with Portland Cement make strong building panel and corrugated roofing sheet. The panel can be used both for partition and walling. (UN Publication, New York, 1976); A research report in 1984 from the Royal Institute of Technology,

Stockholm, Sweden, gives a description of small-scale production of cement-bonded straw (Hermansson, 1993). This shows that compressed straw slabs were used initially as a building material and was almost abandoned but now, its utilization and development is receiving world attention especially in developing countries.

2.2.4 TYPES OF COMPRESSED STRAW BUILDING SLABS

Compressed straw building slabs slightly differs from one another. This variation depends on the type of straw and the binder used; otherwise, the straw slab is basically the same. Also, it is produced under various names. These are: Solomit, Stramit, Rice-husk slabs, wood-wool slabs, cement-bonded straw, straw-caly, Heraklith, e.t.c.

2.2.4.1 SOLOMIT

This is a compressed straw building slab produced from well pressed bales of straw weighing about 40kg, and about 0.5m width plunged into a cement slurry and built up on a concrete foundation (Bainbridge et al, 1989).

The bales could be fixed by hardwood pins stuck down through several bales, or be threaded on steel sections grouted in the foundation. The corners are reinforced by angle bars with wire mesh fixed on both sides for further reinforcement. Its density is about 300kg/m3 with thermal conductivity $\lambda = 0.07 w/m^0C$. The thickness ranges between 30 - 50 mm and a width of 1600mm. It was used in Sweden during 1960 - 1965 and then replaced by other material.

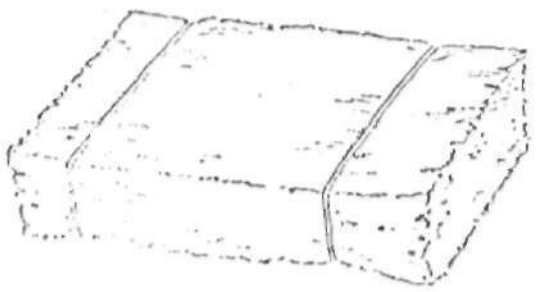


Plate Ia - A Unit Solomit (Straw Slab).

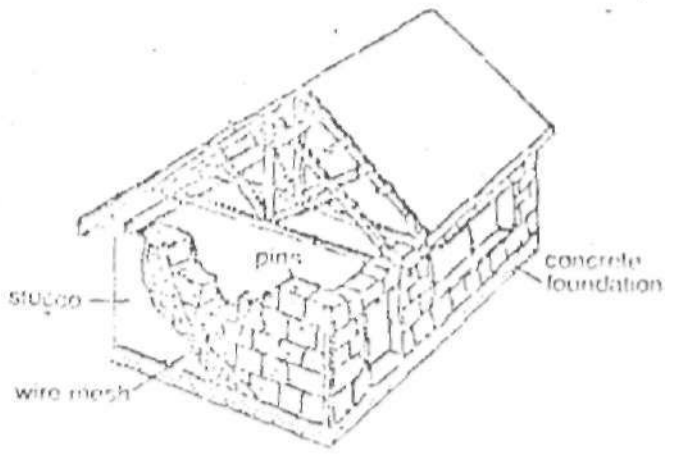


Plate Ib - Application of Solomit to Building Construction.

2.2.4.2 STRAMIT

Is an insulating straw slab made from a cleaned wheat straw, impregnated against rot, and pressed under temperature of 280°C. It was invented by Theodor Dieden in Sweden in 1935. It has a density of 300kg/m3, thickness between 38 - 50mm, width is between 600 - 1200mm and thermal conductivity λ = 0.07w/m°C. Stramit can be plastered, painted or glued on either side with a cardboard or only on one side and bitumen felt on the other. It was used as a building material up to 1960s in Sweden, where it was replaced by other materials but still made in several developing countries for their rural housing programmes (Hermansson, 1993).

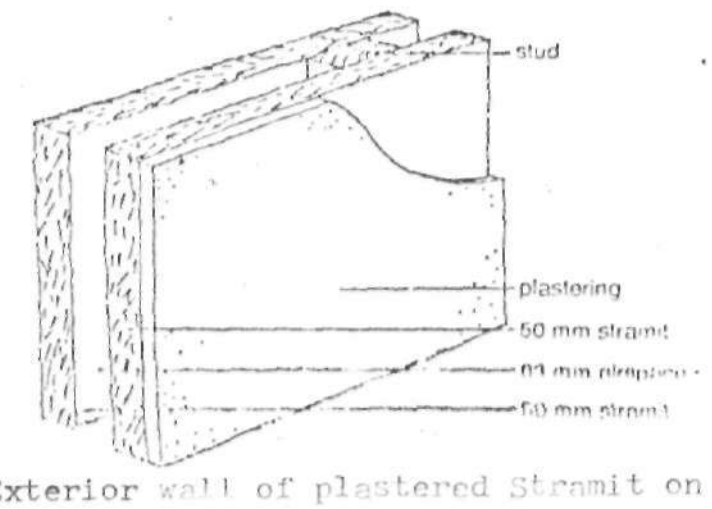


Plate II — Exterior wall of plastered Stramit on joists.

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2.2.4.3 RICE-HUSK SLABS

This is a thermal insulating cement-bonded slab produced using rice husks at the Instituto E Torroja de la Construccion Y del Cemento, Madrid, Spain (Sala et al. 1986).

The rice husks are soaked for 24 hours in a 5% lime solution and mixed with a cement slurry with a water/cement ratio of 0.755.

The weight proportion of rice husks to cement ranges between 28% to 72%. The density of the slab is 824kg/m3 and its thermal conductivity = 0.12 W/M oC and a flexural strength of 0.92 N/MM2.

2.2.4.4 WOOD WOOL SLABS

This kind of slab is chiefly made from wood-wool. Wood-wool unlike straw is normally manufactured from spruce and other kinds of wood using a shredding machine. The wood wool is then soaked in a solution of calcium chloride (CaCl2) for about 24 - 48 hours and then pressed to remove the water. It is then fed together with cement into a mixer. The mixture is then continuously fed into moulds and these moulds are stacked together and pressed in a local press or with known weight on top. The compressed slabs are left to harden for 24 hours and then stripped mechanically. The edges are trimmed and cleaned and the slabs are left to cure for 2 - 3 weeks.

The wood-wool slab gives good thermal and acoustic insulation, with a thermal conductivity λ = 0.08 - 0.13w/mk. Elmroth et al (1968) has shown that it is not necessary to seal the inside of a wall made of wood-wool slab, thereby reducing the acoustic



insulation, to preserve thermal insulation capacity. The absorption of moisture by the unsealed slab surface is not enough to affect the wall's thermal insulation.

2.2.4.5 CEMENT-BONDED STRAW SLAB

This kind of slab is produced using straw and cement as a binder. It was first produced at the Royal Institute of Technology, Stockholm Herlitz et al (1984). The straw is soaked in a solution of calcium chloride (CaCl2) for about 24 - 48 hours and then pressed to rid it of the solution. A mix of 30% straw and 70% cement is then fed into moulds and compressed by a load of . After hardening for two days, the slabs are stripped and then oven dried at 50oC for another 48 hours and then finally allowed to cure. The slabs has good thermal conductivity which ranges between 0.07 - 0.08 w/mk. It provides a good base for plastering and apparently difficult to ignite in a fire test.

2.2.4.6 STRAW-CLAY SLABS

This kind of slab is produced using straw and clay as binder. It was first produced in West Germany immediately after the second world war in order to facilitate the construction of over 100,000 dwellings in the rural areas, where there was no cement or coal for local brick making (Ekblom, 1990). Straw-clay is produced by spreading the straw on a work surface and sprinkling clay slurry over it after which it is mixed using a pitch fork.

The mix is cast between wooden forms to make walls, with forms/formwork that are gradually moved upwards. Compression is light in order to achieve low density so that the wall can serve for thermal insulating purposes only. Straw-clay can be made in varying densities (300 - 1200kg/m3), depending on the degree of compression and the proportion of straw to clay. As earlier said, the lighter mix serves for only thermal insulating purpose while heavier mix functions as both thermal insulating and supporting material. It is fire proof and has a good sound insulating capacity.

2.2.4.7 HERAKLITH

This is a slab produced based on wood wool and cement or magnesite. It was first invented in Austria in 1908 (Hermansson, 1993). It is now manufactured in many countries in lengths of 2.0 - 2.5m, 500 - 600mm width and 15 - 150mm thick, with a density of 250 - 500 kg/m3. It has good acoustic absorption, thermal and acoustic insulation capacity, offers a good resistance to fire and insects or pests (Astrand et al. 1993). Basically, Heraklith is the same with woodwool slabs.

2.2.5 USES OF COMPRESSED STRAW BUILDING SLABS.

Compressed straw building slabs have a number of good properties. Both wood wool and other types of straw slabs have good thermal insulation property, are light weight, simple to use, difficult to ignite, good acoustical absorption, adequate strength,

durability, good moisture, resistance to pests and aggressive environments.

Consequently, they are mainly used as thermal insulating materials, walling material and plaster base in walls. They are also used for sound absorption in walls and floors and as covering board. Depending on density and thickness, they are used as permanent formwork for a load bearing concrete beams and slab.

2.2.6 ADVANTAGES AND DISADVANTAGES OF COMPRESSED STRAW SLABS

ADVANTAGES:

Compressed straw slabs have some economic advantages:

(a) It is easy to produce and instal.

(b) It's components and basic materials are cheap and readily available (agricultural wastes).

(c) By the time the industries for their products are established and functioning, cost of building materials and provision will be reduced considerably.

(d) The production of these slabs does not require expensive equipment(s).

DISADVANTAGES

(a) It lacks a smooth and fine finish.

(b) It is not suitable for exterior application without a "finish".

(c) It cannot be used in damp unventilated areas.

2.3 SOURCES OF RAW MATERIAL FOR THE SLABS: THE RICE PLANT

2.3.1 RICE PRODUCTION IN THE WORLD

Rice has been cultivated for such countless ages that its origin must always be a matter for conjecture. Archeological reports has it that survey from India shows that four terrace built for rice cultivation on the banks of the River Ravi in south-west Kashmir dates to the pleistocene or ice age (Hogan, 1970).

Botanists believed that the plant has its origin from the wild species and with available evidence, conclusion is that the centre of origin of Oryza Sativa linn is south-east Asia, particularly India and Indo-China, where the richest diversity of cultivated forms has been recorded (Chandraratna, 1964).

According to (Grist,1975), mode and date of introduction of Oryza Sativa linn to West Africa is unknown; probably it was introduced by Portuguese traders who visited the coastal regions or possibly, it came across Africa by the Caravan desert routers or may have been already in cultivation in West Africa when the first Portuguese arrived as suggested by Jordan, (1965).

The paddy plant is grown in countries enjoying a sub-tropical or warm-temperature climate and also thrives over a wide range of conditions within about 45o latitude north and 40o south of the equator. (Central America, half of U.S.A.; the West Indies, most of South America, the Entire Continent of Africa, Australia, India, most of China, Japan, the Malay Archipelago and the Pacific Islands).

It is an annual (sometimes perennial) plant with a fibrous root system, culm (stem), leaves and panicles. (Plate 2.3). In many varieties, the plant tillers freely and usually bear four or five culms that grow 60 - 240cm tall. (Plate 2.4).

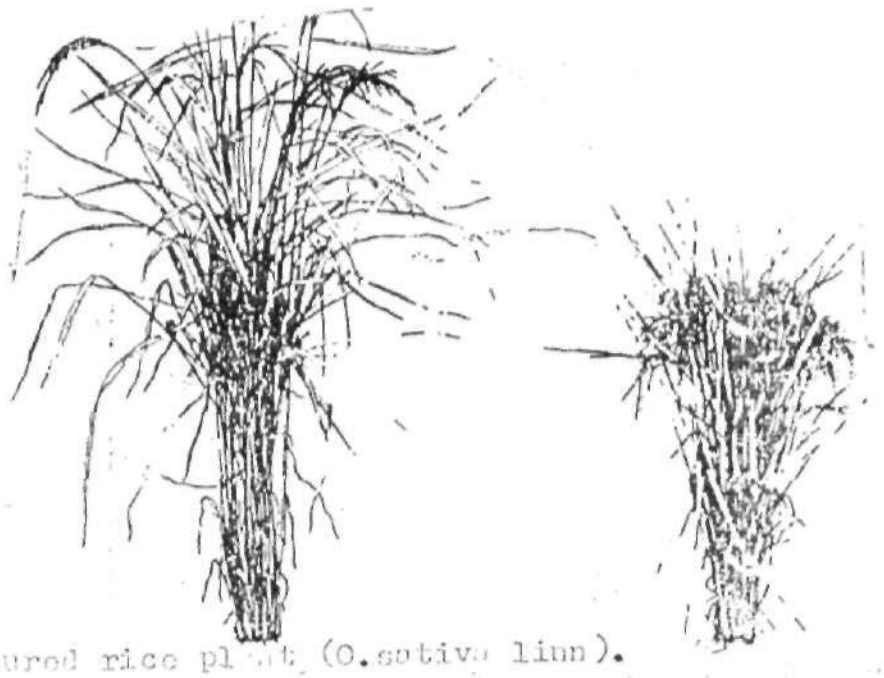


Plate III - A matured rice plant (O.sativa linn).

Botanically, rice is a grass (Graminne) belonging to the genun oryza linn of which two species are cultivated - Oryza sativa linn and Oryza glaberrima stend. The former (O.Sativa Linn) is by far the more important; O. glaberrima being confined to small areas in West Africa. Numerous varieties abound.

The International Rice Research Institute (IRRI) collection numbers over 14,700 whose ultimate weight is 1.22 - 1.33 meters apart from the so called floating varieties. Rice is generally grown on heavy soils with high, fine clay and silt content in order to reduce seepage into the subsoil. Most rice soils have a pH of between 4 - 6 and an annual rainfall of 280 - 200mm.

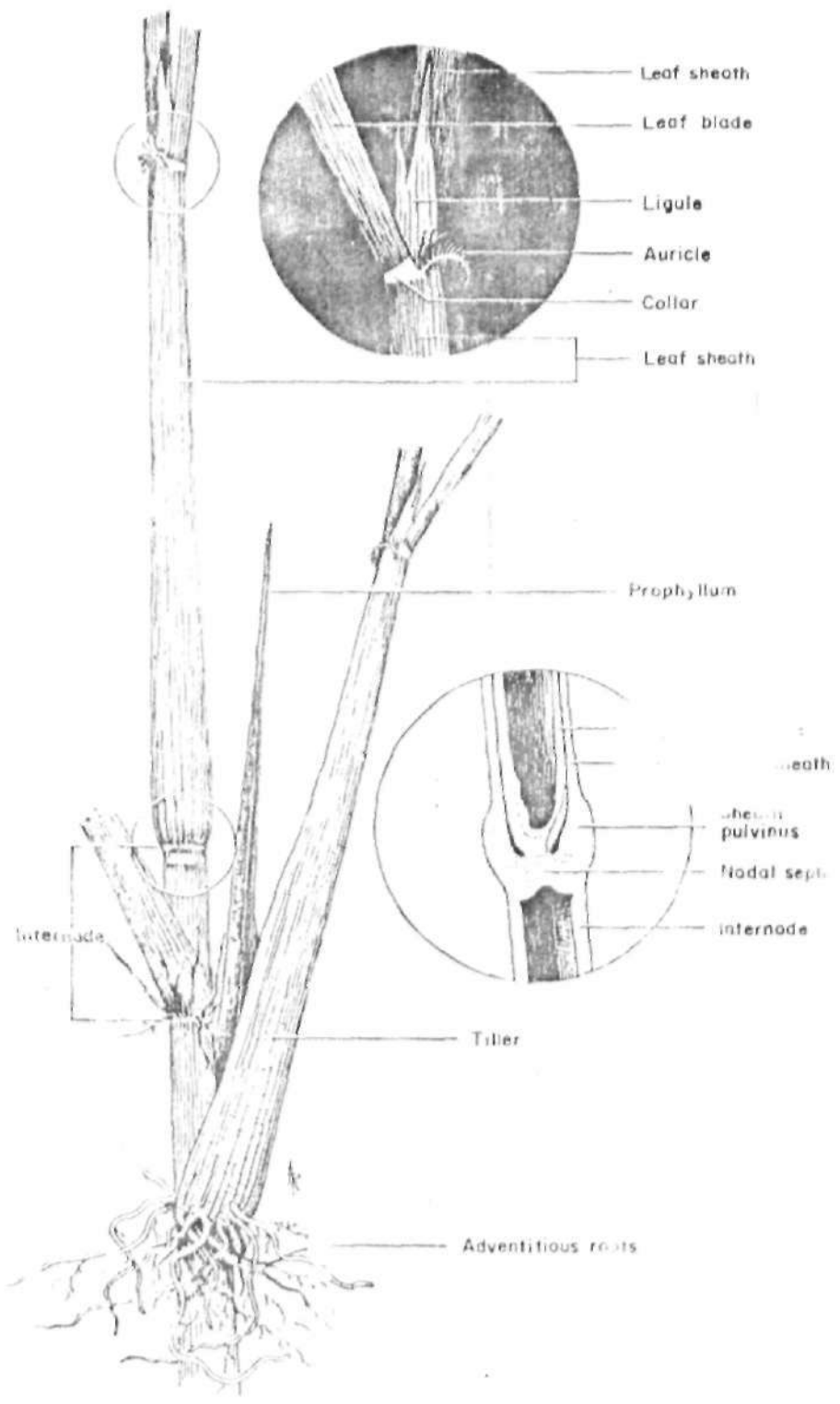


Plate iv - Main parts of a rice straw.

Except irrigated, rice will not grow in areas with less than 280mm rainfall. Rice is primarily grown for its seeds. The straw until recently is chiefly burnt as waste, used as fuel and other uses e.g. rice husk ash as a partial replacement of cement for construction work (Olekwu Ella, 1992).

The seeds are used primarily for human consumption. It is one of the leading food crops of the world, the staple food of over half the world's population (Lu and Changi,1980). Annual world production of rough rice approaches that of wheat and corn (F.A.O. 1982). is 443.9Mt (Million tonner). Annual production in Africa is 8.3mt (F.A.O., 1982). The world yield of rice in tonnes/hectare (t/ha) is 2.8, Africa is 1.8, with Oceanian countries having the highest yield of 5.8 tonnes/ha. (F.A.O., 1982). The world's average yield is 3.2 tonnes/hectare (F.A.O., 1985).

Table 2.1: Annual Production of Cereal Crops by Region

Mean for 1979 - 1981

Annual Production (Million Tonnes)									
Area	Wheat	R/Rice	Corn	Sorghum	Millet	Barlley	Rye	Oat	Total
Africa	8.7	8.4	28.0	10.5	10.1	3.8	0.01	0.2	71.3
North./Central America	89.3	9.1	212.8	24.7	0	20.4	1.1	10.4	370
South America	12.2	13.4	32.6	6.9	0.2	0.9	0.2	0.8	67.3
Asia	133.1	360.2	84.8	20.2	16.4	16.3	1.8	1.2	639.6
Europe	91.6	1.9	54.2	0.7	0.03	68.8	12.6	14.3	247.7
Oceania	14.8	0.7	0.3	1.1	0.02	3.5	0.01	1.4	21.9
USSR	92.1	2.5	8.6	0.1	1.6	44.8	8.9	15.2	175
World	443.9	396.3	421.4	64.3	28.5	158.5	24.7	43.5	1592.8
No. of countries producing	102	112	146	84	66	81	42	55	165

Data from FAO (1982).

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e 2.2 - Mean Grain Yield of Cereal Crops by Region Mean for 1979 - 1981

Region	Mean Grain Yield (t/ha)								
	Wheat	Rough Rice	Corn	Sorghum	Millet	Barley	Rye	Oat	Total Cereals
Africa	1.1	1.8	1.3	0.7	0.6	0.8	0.2	0.5	1.0
North and Central America	2.2	4.4	5.4	3.3	0	2.5	1.7	1.9	3.5
South America	1.3	1.8	1.9	2.7	1.2	1.2	0.8	1.3	1.8
Asia	1.7	2.8	2.3	1.0	0.7	1.5	1.3	1.5	2.1
Europe	3.6	5.1	4.6	3.6	1.6	3.4	2.3	2.7	3.5
Oceania	1.3	5.8	4.1	2.0	0.8	1.3	0.5	1.1	1.3
USSR	1.5	4.0	2.9	1.1	0.6	1.3	1.9	1.3	1.4
World	1.9	2.8	3.3	1.4	0.7	2.0	1.6	1.7	2.2

* Data from FAO (1982).

2.3.2 RICE PRODUCTION IN NIGERIA

Nigeria is a major rice producer among the West African countries. Under normal conditions, it accounts for about 20% of the acreage and nearly 25% of the production of the 11 West African countries surveyed. (Rice in West Africa - A study by U.S. Department of Agriculture and Agency for International development. Washington D.C. 1968).

The production capacity has been rising steadily in recent times. At an annual growth rate of 30% and a projected population of 95.5 million people with consumption rate at 20kg/head, Nigeria's production capacity at the end of 1990 stood at 3.86 million tonnes. (see table below).

Table 2.3: Projected Rice Demand and supply in Nigeria

(1985 - 1990)

Year	Population (10^6)	Rice Demand at 20Kg/head (10^6)	Production potential (10^6) at growth rates (%) of:			
			3.5	10.0	20.0	30.0
1985	84.00	1.68	0.85	0.88	0.96	1.04
1986	86.18	1.72	0.86	0.97	1.15	1.35
1987	88.42	1.76	0.89	0.06	1.38	1.76
1988	90.72	1.81	0.92	1.17	1.66	2.28
1989	93.08	1.86	0.95	1.29	1.99	2.97
1990	95.50	1.91	0.98	1.42	2.39	3.86

Source: The wetlands and rice in subsaharan Africa by A.S.R Juo and J.A. Lowe. Proceding of International Conference on wetland utilization for Rice production in Subsaharan Africa. Nov. 4-8 1985; Ibadan, Nigeria.

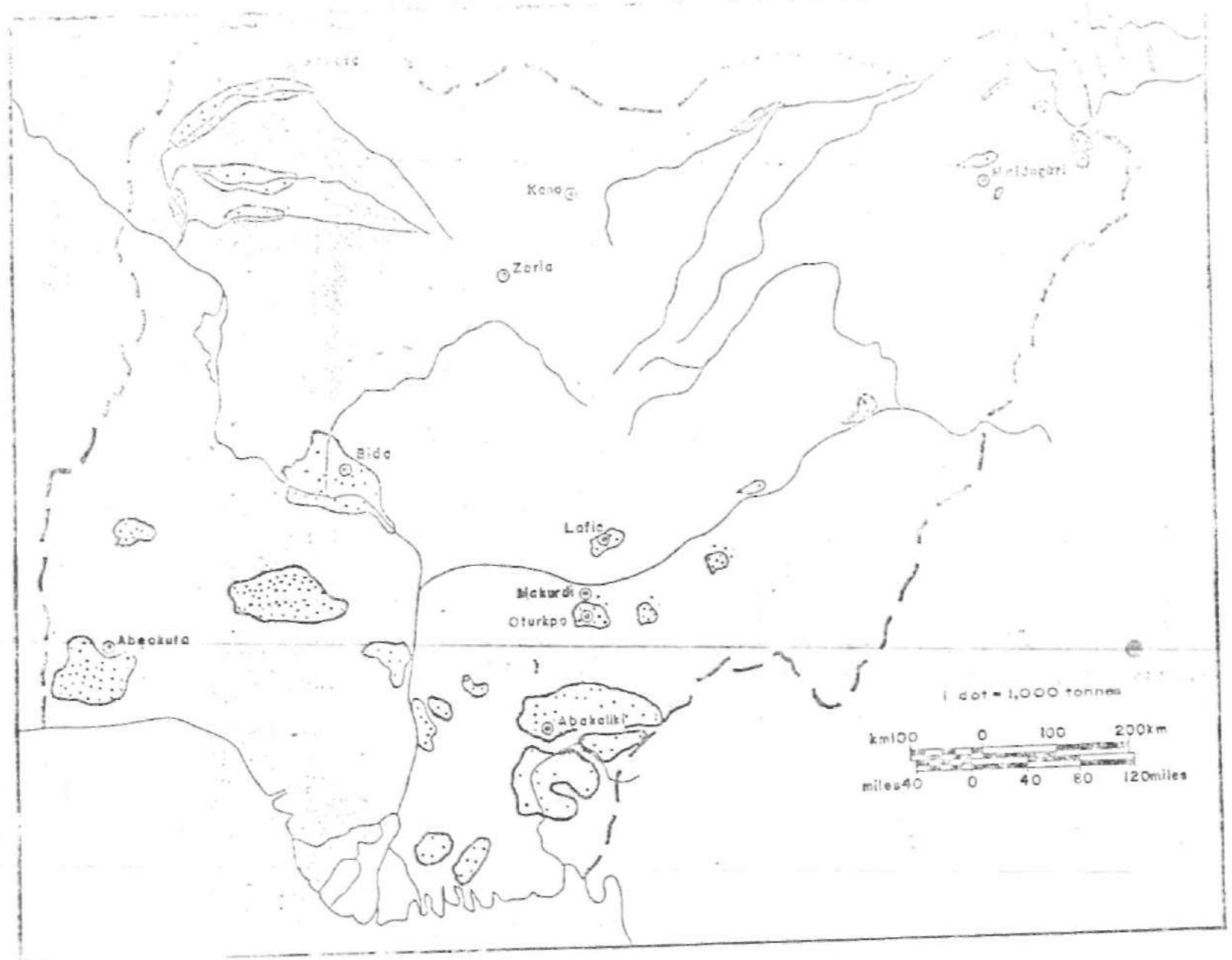


Plate V - RICE Producing Areas in Nigeria

Rice is a cereal crop. In Nigeria, its consumption is increasing rapidly and in some instances it is the preferred staple food for children. In the Northern region, millet and sorghum (Dawa) have been the traditional staple food. The bulk of rice consumption is probably in urban centre due to the fact that food habits are more flexible than is true for rural groups.

Nigeria rice production area have been classified into four typical resource situations. These are:

(1) The upland areas, possibly the most extensive in acreage, but relatively less important in production.

(2) The naturally inundated land along the rivers (fadamas) of Northern Nigeria and the small inland swamp in Eastern Nigeria which are the most important production areas.

(3) The recently-developed-irrigation scheme throughout the country.

(4) The fresh-water tidal mangrove swamps found largely along the souther coastlines. (Plate v show rice production areas in Nigeria).

Rice is primarily grown for its seeds. When harvested and milled is mainly used for food. The by-products like the hull and the straw are wastes and the major means for disposal is by burning.

2.3.3 USES OF RICE

Because of its high cost, the milled grain is used mainly for food. Rice starch production is quite limited because of the high

cost of brewer's rice. The European Economic Community (E.E.C.) produces only 7,000 tonnes of rice starch annually in factories in Belgium, germany, Netherlands and Italy (Kempt, 1984). Brewer's rice is used mainly in the fermentation industry.

Rice is also used in other products like baby foods, breakfast cereals and yeast-leavened rice bread in U.S.A.

2.4 THE RICE STRAW AND ITS USES.

Straw is the major residue of rice production, and hull is the major by-product of rice processing. With modern rice varieties, straw production is at least equal to rough rice yield, based on a harvest index (ration of grain to grain plus straws) of 0.5 (Yoshida, 1981). Tall, traditional varieties with a harvest index of 0.3 produces more straw (Yoshida, 1981). Relatively less hull is produced, representing about 20% of rough-rice weight. Based on the estimated rough-rice production for 1981 - 1982 of 400mt (USDA, 1982) the estimated annual production of rice straw is at least 400mt and of hull, about 80mt. Both straw and hull are fibrous in nature and rich in cell walls and have feed value only in ruminants, with straw being more nutritious than hull.

STRUCTURE

Rice straw consists mainly of culm (stem), leaf sheaths, and the remains of the panicle after threshing. It can vary in length from one to two meters for most widely grown irrigated types but can be up to seven meters in floating or deep-water rice due to

internode elongation (Chang and Bardens, 1965). Secondary tillers are produced as branches of the primary tiller at the nodes; maximum tillering occurs 40 - 60 days after transplantion (Vergara, 1980).

THE CULM

Is composed of a series of nodes and internodes and is enclosed within the leaf sheaths, except the portion just below the panicle after heading. Yoshida, 1981 and Jones, 1975 explored the structure of rice straw by scanning electron microscope (SEM) and revealed that the culm consists of an epidermis, cortex, and pith. (Plate 2.3).

THE LEAF SHEATHS

The rice leaf is composed of the sheaths, the blade, the ligule and the auricles (Yoshida, 1981). The sheath is an enlongated, ribbon-shaped leaf. Most early to medium-maturing varieties develop about 10 - 15 leaves (Yoshida, 1981).

THE PHYSICAL AND CHEMICAL COMPOSITION OF THE RICE STRAW

Physical composition - The physical state of the straw is that it is solid and its components' composition are as shown below (table 2.5).

Table 2.4 Comparative Physical Composition of Rice Straw and other Cereal Straws. (% dry weight)

Cereal	Stem and Stem Nodes	Leaf Sheaths	Leaf Blades	Rachis and Chaff	Grain	Debris and Fines
Rice	32.4	33.1	16.4	11.9	0.7	5.5
Wheat	68.5	20.3	5.5	4.2	1.0	0.5
Barley	58.8	31.5	4.9	1.8	1.1	1.9
Rye	68.1	19.8	2.9	7.4	1.3	0.5

Source: Brust et at (1960): Technical Association of the Pulp and Paper Industry; used by permission.

Table 2.5 Comparative Chemical Composition of Rice Straw and Other Cereal Straws.

Constituent	Rice Straw	Corn Straw	Wheat Straw	Oat Straw	Barley Straw	Rye Straw	Millet Straw	Serghum Straw
Crude protein % N X 6.25	2.8-4.4	5.6-5.8	2.2-3.6	2.5-4.0	3.5-4.2	2.9-3.2	3.6	2.9-5.4
Crude fat, %	1.1-1.3	1.2-1.5	1.4-1.6	1.5-1.8	2.0-2.1	2.0-2.1	1.5	2.1
Crude fiber, %	26.0-33.9	29.2-36.6	34.4-39.6	29.0-36-	34.8-39.1	35.9-46.0	35.8	28.0-35.9
Available carbohydrates %	39.2-40.6	44.1-48.0	38.9-43.0	39.2-44.0	39.2-42.3	41.7-42.5	39.8	50.9
Crude Ash, %	10.4-21.8	3.7-7.0	5.5-8.3	5.5-9.3	3.8-7.8	3.2-4.6	5.3	5.2-9.7
Calcium, mg g	11-15	....	5	3-4	3	...	...	3
Lignin %	0.9-5.0	5.1-5.2	1.4-1.8	2.1-3.2	2.2-2.3	2.4	0.8	4.1
Phosphorus, mg/g	0.61-0.65	0.8-0.9	0.7	0.8-1.0	0.6-0.9	0.8	...	0.9
Lignin, %	5-11	7-13	8-14	6-12	9-15	1.6	...	7-12
Cellulose, %	24-34	22-35	34-48	29-38	29-38	31-32	...	27-36
Pentosans, %	15-21	14	11-16.24	16-24	23-24	25-26	...	15
Hemicellulose, %	19-29	28	19-31	20-23	14-21	...	..	26-27
Neutral detergent fiber, %	48-72	58-70	69	66-72	60-71	...	...	64-70
Acid detergent fiber, %	39-48	34-49	38-49	46-51	40-49	...	...	42
Total digestible nutrients %	19	49-51	38-40	40-42	41-43	3 9	41	41

Source: Data from Millea et al (1982).

USES OF RICE STRAW

Presently, rice straw is disposed by burning in Nigeria, however, extensive research work is being conducted towards a better and useful utilization. Similar investigations are on Bagasse, a major by-product of sugar production, cupatorium odorata and pennisetum purpareum i.e. elephant grass, coconut husk, rice straw and groundnut shell. (Journal of the Network of African countries.)

However, in Europe and other parts of the world, extensive research has already been carried out and useful results obtained. In the light of this, in Europe the straw is used for the following purpose:

(1) Used for animal feeds after treatment (Ranjhan and Beagle, 1978), Doyle, 1982, 1984, 1985; Pearce, 1983 to reduce its indigestibility.

(2) Used in Biomass conversion - Biomass conversion depends on the breakdown of the ligno cellulose residues of rice hull and rice straw into sugar which are then converted to other organic chemicals (Del Rosario, 1985) e.g. in saccharification and production of ethanol and furfural.

(3) Used in sugar fermentation - saccharification and ethanol fermentation of rice straw was recently reviewed (Wald et al. 1981, Del Rosario, 1985, Ghose and Mishra, 1985). The conversion of rice straw into ethanol may be achieved in a single-stage or a two-stage process.

(4) Agricultural uses:

(a) With increase in cost of fertilizers, rice straw is used as a

source of nutrients for wetland rice production (Ponnam Perum, 1984).

(b) Used in composting - Addition of fresh rice straw into the soil for 12 weeks without the addition of Nitrogen source decreases carbon content of the soil and gradually increases total Nitrogen content (Inuko, 1982).

(c) Used as Bedding material for growing tropical mushrooms of various kinds (Alicbusan, 1985).

(5) Building materials and other uses.

(Chittenden and flaws, 1964) showed that rice hull can be used successfully as an aggregate in the production of light weight concrete building blocks, provided presoaked hull was (1:00:0.25:0.35 for cement, hull and water by weight) and pressure moulding was practiced.

Fibre boards: Shukla et al. (1983) described three thermo mechanical processes for making high density boards from rice hull powder. For binderless board, the powdered hull (0.25 - 0.39) was mixed thoroughly with 2% by volume of concentrated sulphuric acid or 5 - 8% by weight of hull and was sun dried. The board was pressed at 60 - 70kg/cm2 for 20 - 25 mins at 165oC or 12 - 15 minutes at 175 - 200oC.

OTHER USES OF RICE STRAW

- Traditional uses of rice straw in Japan in addition to organic manure include the manufacture of rope bags and of "Tatami" floor mats (Sakurai, 1977).

- Used for fuel:- disposed by burning in an open field. Each ton of dry straw burned emits 4.1kg of particles, 38kg of carbon monoxide and 4.5kg of hydro carbons (Debil and Mosley, 1981).
- In India, paddy straw is extensively used for weaving mats and bags. The straw is readily available for the established paddy strawmat loom (M. M. Rashyap and Ama Singh, 1982). See below.

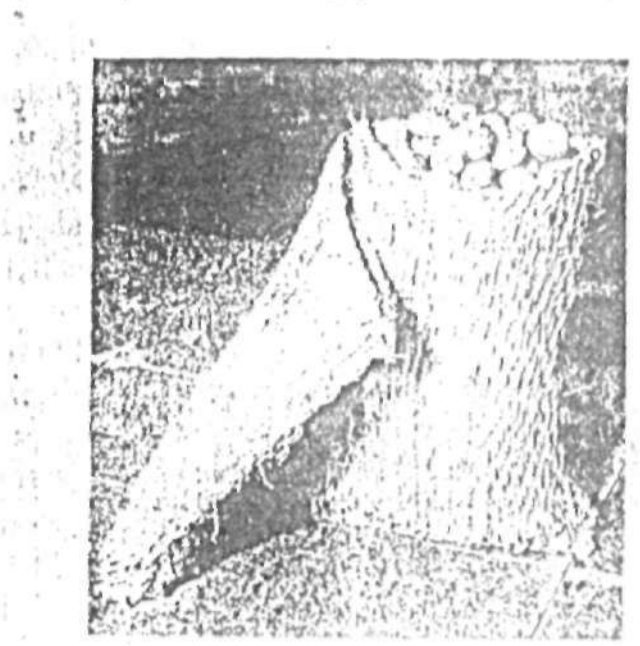


Plate VI - Paddy Straw Utilisation for Bags and Mats

2.4.1 SUITABILITY OF RICE STRAW IN COMPRESSED STRAW BUILDING SLAB PRODUCTION

The suitability of the raw material to be used in the production of compressed straw building slab is essential. Precisely. it is the main aim of this study. Consequently. knowledge of the physical and chemical properties of the raw material is necessary in order to know the constituents of the raw material and its limitation for the intended purpose. In the light of this. the physical and chemical compositions of the rice straw were studied.

The values given were got from literature and they are values for same variety the author has chosen: since the differences in quantitative constituents are insignificant, and the author safely assume the figures to represent the constituents of the rice straw for the research.

The physical composition of the rice straw consist basically of the stem (culm). leaf sheaths and blades. Rachis and Chaff. grain, debris and fines. (see table 3.4). The main chemical constituents of the rice straw are crude ash and fiber. silica. lignin, cellulose, pentosans, Hemi cellulose, Neutral and acid detergents and carbohydrates (see table). These are mainly from the stem, leaf sheaths and blades. Leigh, (1980) has shown that cellulose and lignin enhance board manufacture. Also. the presence of pentosans (15 - 20%) explains why it is used in the production of furfural.

Presence of acid normally affects the properties of the

materials. Since there is no acid, the properties of the compressed straw slab will not be affected moreover, the presence of the detergents will further protect the material.

This is because Foster (1967) has shown that the presence of acid affects the quality of particle boards. In addition, the Forest Products laboratory, a division of the Federal Institute of Industry Research (FIIR) Oshodi, Lagos, Nigeria in investigating a better use of some agricultural residues, carried out a research on residues among them is rice, The results got were quite encouraging for example, particle board produced from rice straw has a density of 600 kg/m^3 bending strength of 1.25 N/MM2, water absorption of 59% and a thickness swell of 11% using a resin content of 8 %.

In the light of these developments, the author safely assumed that rice straw will be suitable in the production of compressed straw slabs; consequently, the straw was then used to manufacture compressed straw slab samples. The process of production are outlined in the next chapter.

2.5 THE GUM ARABIC

Gum Arabic is a hard substance obtained through incision on the trunk of the tree, Acacia Senegalis. It is commonly found in the far Northern parts of Nigeria and other parts of Africa like Senegal, Tunisia Libya, and Tanzania. The tree has featherly leaves and white flowers, thorny and about 7.6 meters high.

The Gum is produced by making an incision in the bark of the

tree. This makes the gum exude slowly in places around the cut and eventually dries into small lumps. The lumps usually appear in various colours and about the size of a walnut.

The lumps otherwise called "tears" are collected, bleached in the sun and then sold locally or exported.

Through chemical analysis, the gum is found to consist of compounds of neutral salts such as potassium, magnesium or calcium of acidic polysaccharides. It is soluble in water and used in many products e.g. in confectionery, cosmetics, textiles, paper, e.t.c. (Encyclopaedia Britannica, Vol. 10, 1975, Page 1084).



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Plate VII - The Gum Arabic

2.5.1 ECONOMIC IMPORTANCE OF THE GUM

On commercial basis, Nigeria is the second largest producer and exporter of Gum Arabic in the world, producing over 10,000 metric tonnes yearly. In Nigeria, the tree grows in the forest zone but on commercial quantities, it is produced in states like Yobe, Adamawa, Taraba, Kano, Sokoto, Zamfara and Kebbi. Efforts are being intensified by the Borno state government to establish its commercial plantations.

It is disheartening that this product is currently being exported to Overseas countries in crude form at relative cheap prices and re-imported into the country as the purified gum at higher prices. The refined product finds application in the food/beverage, packaging adhesive, pharmaceutical, chemical and allied sectors.

Processing or refining gum Arabic is therefore justifiable on the basis that:

(1) Imports of refined gum will now be neatly substituted by locally refined equivalent with a lot of foreign exchange saved.

(2) Export of refined gum)if the industry is established) will largely enhance foreign exchange earnings.

(3) The industry if established will offer employment opportunities to the teeming unemployed. (Odili, 1997)

It can be seen that this will enhance greatly the production of the straw slab in that the processed gum will be readily available and cheaper.

The finished cement is packed in 50kg bags and stored in silos for very large construction work.



Plate VIII - 50 kg bags of cement

CHAPTER THREE

3.0 LABORATORY PRODUCTION AND TESTING OF SPECIMENS

3.1 PROCESSES AND EQUIPMENT

The rice straw used for the manufacture of compressed straw slabs were collected from farms in the outskirts of Sabon-Gari. Zaria, Nigeria. The production of the straw slab was carried out and the following steps were followed in the production of the straw slab.

(a) Rice straw preparation (washing, weighing, etc).

(b) Cutting of the straw into tiny bits between 1cm - 4cm length.

(c) Preparation of the Binder (Gum Arabic).

(d) Mixing of the straw with the Resin.

(e) Formation of a mould and a mat.

(f) Final pressing using local screw press.

(g) Stripping, Trimming and Curing.

3.1.1 WASHING, SOAKING IN SODIUM CHLORIDE (NACL) AND DRYING

The process of manufacture starts with the washing of the straw, the straw is initially soaked in clean water to remove dirts, suspended impurities and debris. To neutralize the effect of carbohydrates which may prevent the resin from bonding to the straw; the straw was soaked for 24 - 48 hours in a solution of 5% sodium chloride (NaCl) per 100 litres of water and then spread out to dry to an average moisture content of 10 -14%, According to Hermansson, (1993).

On drying, the quantity of the straw material used was calculated as shown below.

Nominal density of compressed straw slab = ρ.

Thickness of compressed straw slab = tmm.

Length of forming mould l = lmm.

Width of forming mould b = bmm.

Weight or mass of straw = Mgm

∴ Volume of resulting compressed straw slab = V g/mm^3 = Lxbxt mm^3

∴ Density $\rho = \frac{Mgm}{Vmm^3}$

The amount of straw after pounding into pulp is measured corresponding to this weight or mass = Mgm.

Clause 4 (BS 4046 Part II, 1971) provides that the dimensions of the slab shall be as follows:

Length 1800mm - 3600mm;

Width 1197mm - 1200mm; and the

thickness shall be between 49 and 53mm.

Since a specimen straw slab will be produced and investigated, it was decided to adopt a mould of 400mm x 400mm x 50mm. Clause 9 of the same code specifies that the density of the slab shall be between 340kg/m3 and 440kg/m3.

3.1.2 PREPARATION AND BLENDING OF GUM ARABIC

The resin chosen for this study is Gum Arabic. This is because of its low cost and availability. Gum Arabic is an adhesive substance derived as exudes from the bark of an Acacia tree. As mentioned earlier, this tree is commonly found in the far

areas. The structure and mechanism of this press is described in section 3.1.6.

The mat in the mould was then gently placed in the local press and pressure using the press is exerted and then left to set for 72hrs. The slab was then gently removed from the press and then stripped of the mould. It was then left to cure at room temperature.

3.1.5 CURING

Curing is the process whereby a material manufactured is kept in a cool place so as to minimize or eliminate the effect(s) of environmental conditions on it. The slabs produced were kept in dry cool place for 24 hours. The edges were then trimmed and it was kept in the same cool place again for 30 days before tests were carried out. This is necessary so as to equalise the moisture content throughout slab and thus minimise warping that might otherwise occur

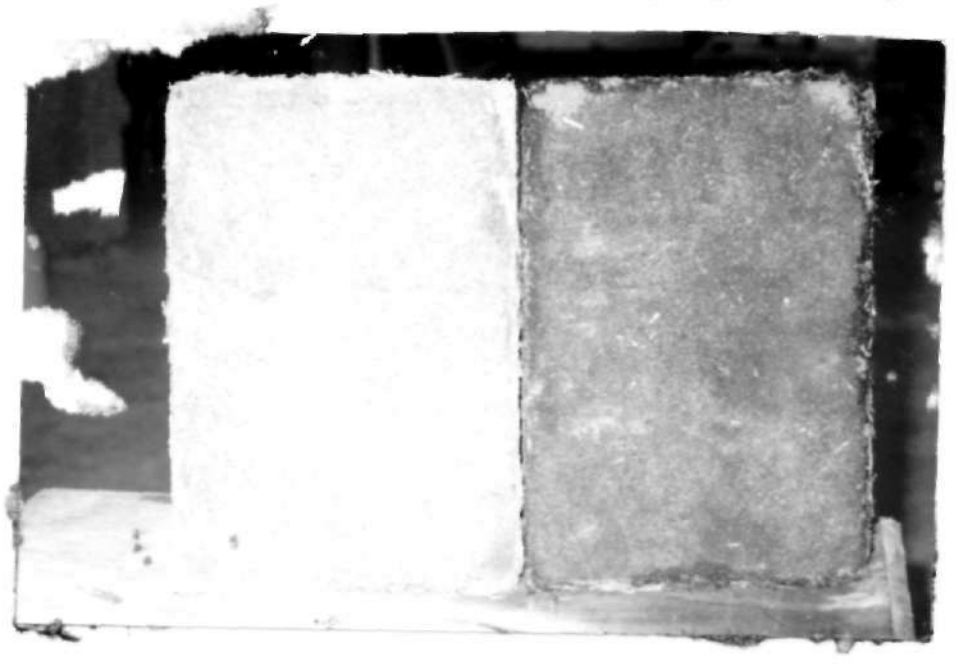


Plate IX - Samples of Compressed straw slabs produced.

Table 3.0 - Percentage Concentration of Binder Used For Sample Specimens

SLAB NO	MASS OF SURFACE DRY STRAW	MASS OF BINDER	% CONCENTRATION of Binder
01	300	700	70%
02	300	700	"
03	300	700	"
04	300	700	"
05	300	700	"
06	300	700	"
07	350	800	"
08	350	800	"
09	350	800	"
010	350	800	"
011	350	800	"
012	350	800	"
032	250	600	"
033	250	600	"
034	250	600	"
035	250	600	"
036	250	600	"
037	250	600	"
BINDER - CEMENT			
013	300	700	70%
014	300	700	"
015	300	700	"
016	300	700	"
017	300	700	"
018	300	700	"
019	350	800	"
020	350	800	"
021	350	800	"
022	350	800	"
023	350	800	"
024	350	800	"
025	250	600	"
026	250	600	"
027	250	600	"
028	250	600	"
029	250	600	"
030	250	600	"

3.1.6 THE PRESS

As mentioned earlier, the author decided to adopt this local press to enable the intended users of the slab to construct it themselves at minimal cost.

The press is 0.8meters high, rectangular and 48kg mass. About 30 cm from the ground is a 400mm x 400mm horizontal metal base on which the mould is placed. There is a central screw jack attached to the pressing pad which is few millimeters less in dimension than the mould. Two thin metal sheets, one placed on top of the base and the other on the mat just before pressing to avoid the surface and bottom of the mat sticking when in contact.



Plate X - The Screw Press used for the study which was fabricated locally.

3.1.7 PROCESS FLOW CHART

The mode of production of the experimental slabs as discussed in the previous section is shown (Fig. 3.1) in a simplified flow chart.

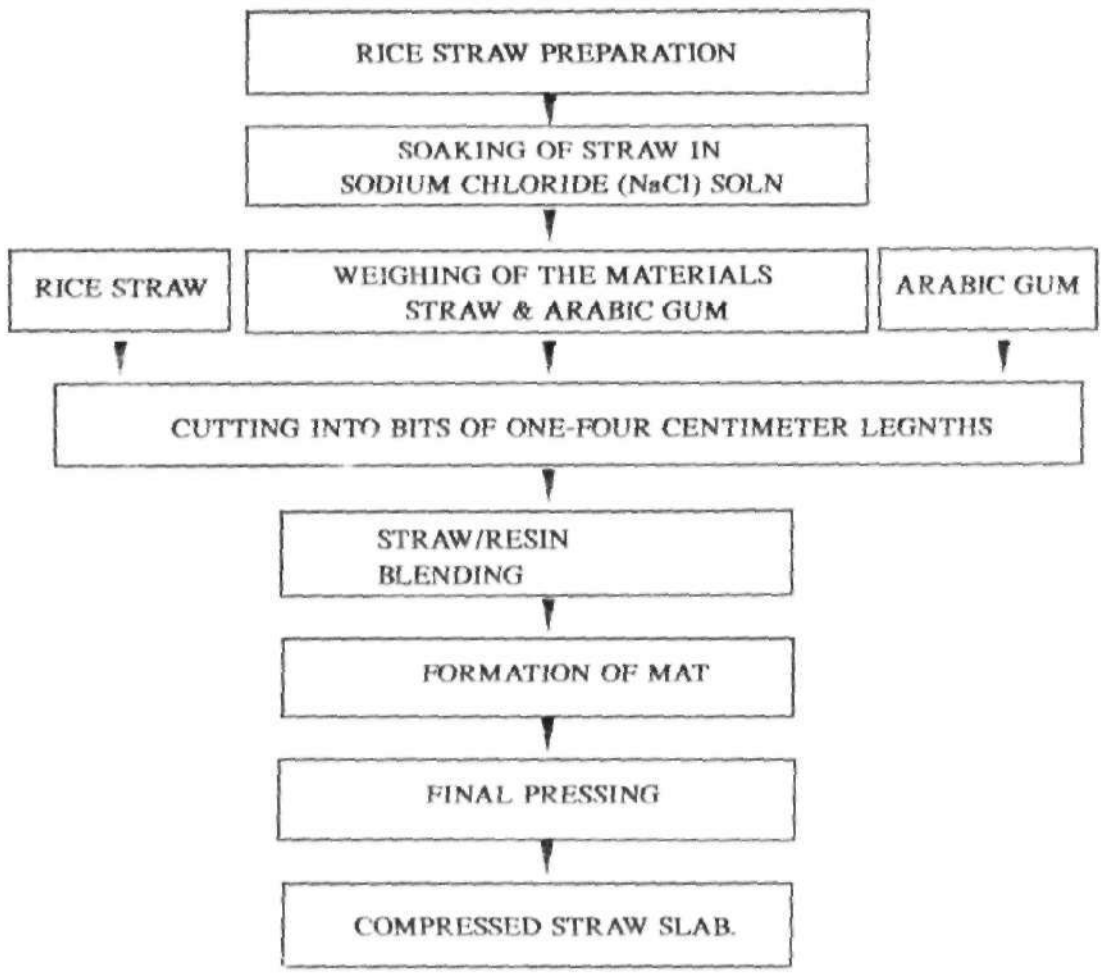


Fig. 3.0 -- A simplified flow-chart of the laboratory production of compressed straw slab from Rice straw.

The slabs were then tested for the evaluation of their physical and mechanical properties and to verify if the values of these properties conform to standards in BS 4046, Part II, 1971. The tests and their procedure carried out are outlined in the following section.

3.2 TESTS OF SPECIMENS

The straw slabs, produced were tested to ascertain its properties (physical and mechanical) in conformity with the specifications (BS 4046, Part I & II, 1966 and 1971). The tests carried out were purely destructive methods of tests.

These tests and its procedures are briefly described below. The tests are done in accordance with the procedures specified in BS 4046, Part I & II, 1966 and 1971 - specifications for tests of compressed straw building slabs and BS 1142 Part II specifications for tests of fibre boards. The results of the tests are shown in the following tables: (3.1 - 3.4); and the following figures (3.1 -4.0). Sample calculations for all tests are shown in Appendices.

3.2.1 DETERMINATION OF DENSITY

After curing the specimens accordingly (Appendix B, BS 4046, Part I & II, 1971), the slab samples were sawn into test specimens. The length of each test specimen was measured to the nearest 3mm and the width to the nearest 1.5mm with the aid of Calliper.

The thickness for each test specimen was also measured in accordance to the provisions in Appendix C of BS 4046, Part II, 1971.

Each test specimen was then weighed in accordance to the provisions in Appendix D of the same code. The volume of each specimen was then calculated as follows:

$$\text{Density } \rho \text{ (rho)} = M/V$$

where = Density - ρ

Table 3.1 - Density of Compressed Straw Slabs Produced

SLAB NO	DENSITY (Kg/m^3)	SLAB NO	DENSITY (Kg/m^3)
GUM ARABIC		CEMENT	
01	215.56	013	387.36
02	332.82	014	392.19
03	326.67	015	402.62
04	310.55	016	390.15
05	330.25	017	376.94
06	215.00	018	428.43
07	325.12	019	402.75
08	328.50	020	403.40
09	345.25	021	443.59
010	365.04	022	445.00
011	391.08	023	465.78
012	394.00	024	487.93
032	201.00	025	390.15
033	250.25	026	403.39
034	225.35	027	393.51
035	300.18	028	486.95
036	325.42	029	466.08
037	275.25	030	493.39
Average Density = 303.17Kg/m^3		Average Density = 425.53Kg/m^3	

3.2.2 MOISTURE CONTENT TEST

The moisture content of the slabs were determined according to the provisions in Appendix E, BS 4046 Part II, 1971. This consists of weighing a test specimen of the slab to an accuracy of and then dried in a ventilated oven at a temperature of 600 ± 2°C until the weight is constant to 0.1g between two weighings made at an interval of not less than one hour. Consequently, the test specimens were initially weighed and then dried in an oven at a temperature of 60°C for 45 minutes and then weighed again.

The moisture content, expressed as a percentage of the oven dried weight, is given by the formula:

$$M_c = \frac{W_1 - W_0}{W_0} \times 100$$

where W1 = initial weight in gm.

W0 = oven dry weight in gm.

Mc = moisture content of the slab (%).

Sample specimen calculations are in appendix

The test results are presented in table 3.2 below.

Table 3.2 - Moisture Content of Compressed Straw Slabs Produced

SLAB NO	MOISTURE CONTENT	SLAB NO	MOISTURE CONTENT
GUM ARABIC		CEMENT	
01	6.0%	013	1.22%
02	9.1%	014	2.50%
03	6.8%	015	3.78%
04	5.96%	016	2.25%
05	8.07%	017	1.06%
06	5.96%	018	5.0%
07	6.43%	019	4.0%
08	7.04%	020	5.15%
09	11.57%	021	7.21%
010	13.64%	022	8.33%
011	13.86%	023	2.67%
012	14.94%	024	4.17%
032	4.96%	025	7.00%
033	5.0%	026	4.17%
034	12.0%	027	3.50%
035	9.06%	028	5.72%
036	7.75%	029	6.65%
037	10.0%	030	5.33%
Average Moisture Content = 8.61%		Average Moisture Content = 5.06%	

3.2.3 THERMAL CONDUCTIVITY TEST

This was done in accordance with the provisions of Appendix H, BS 4046, Part II, 1971 and sub-clause 10a, BS 874. It was done in order to determine the thermal conductivities of the slabs produced.

The procedure is as follows:

The test specimens (130mm x 135mm x tmm) used for the determination of the moisture content were tested to determine its thermal conductivity using the Lee Disc Apparatus.

Details of the test procedure, theory and sample calculations are in Appendix III. Plate XI Below is an adapted version of the test apparatus.

The test results are presented in table 3.3.

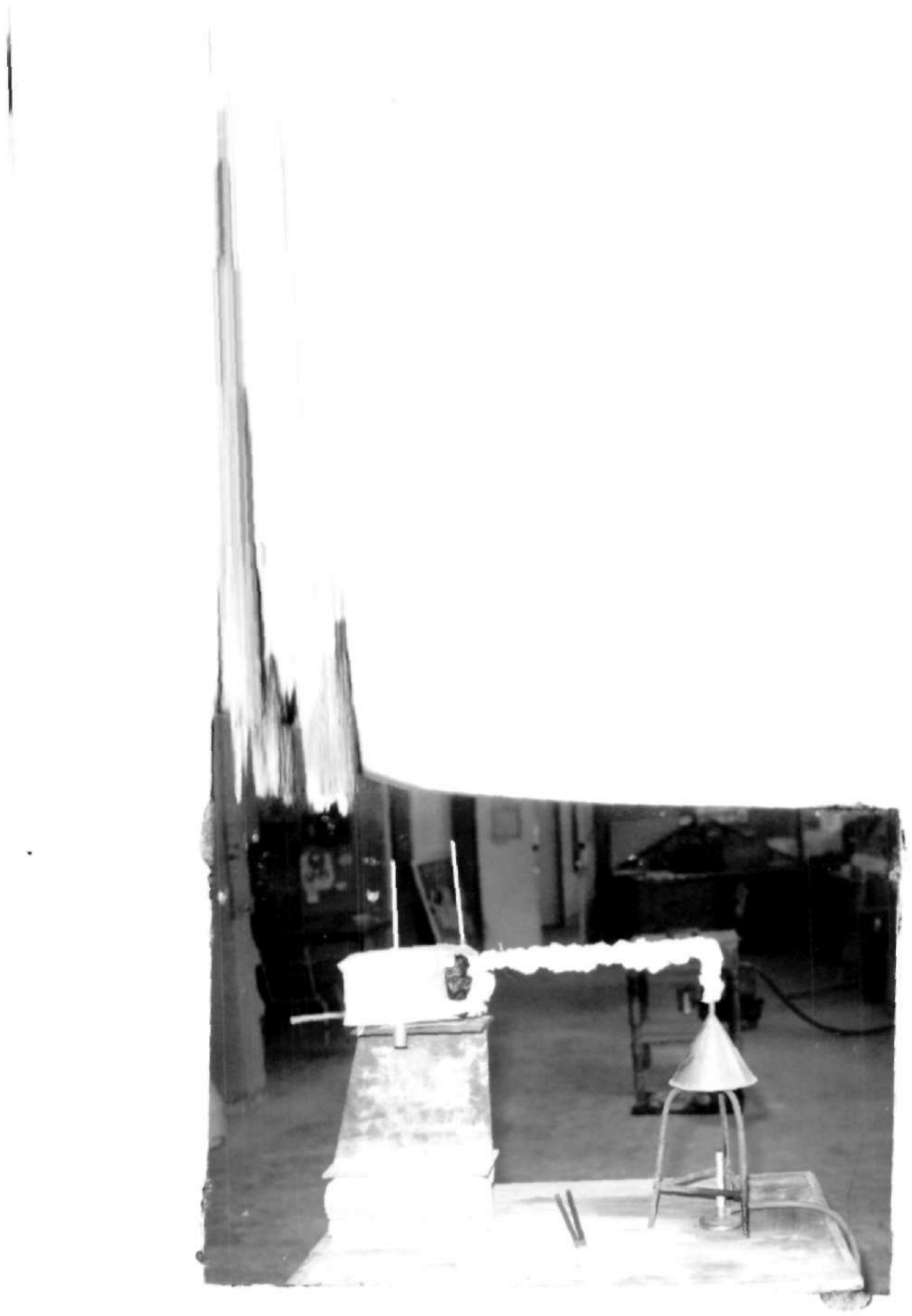


Plate XI - Lee Disc Apparatus (Adapted Version)

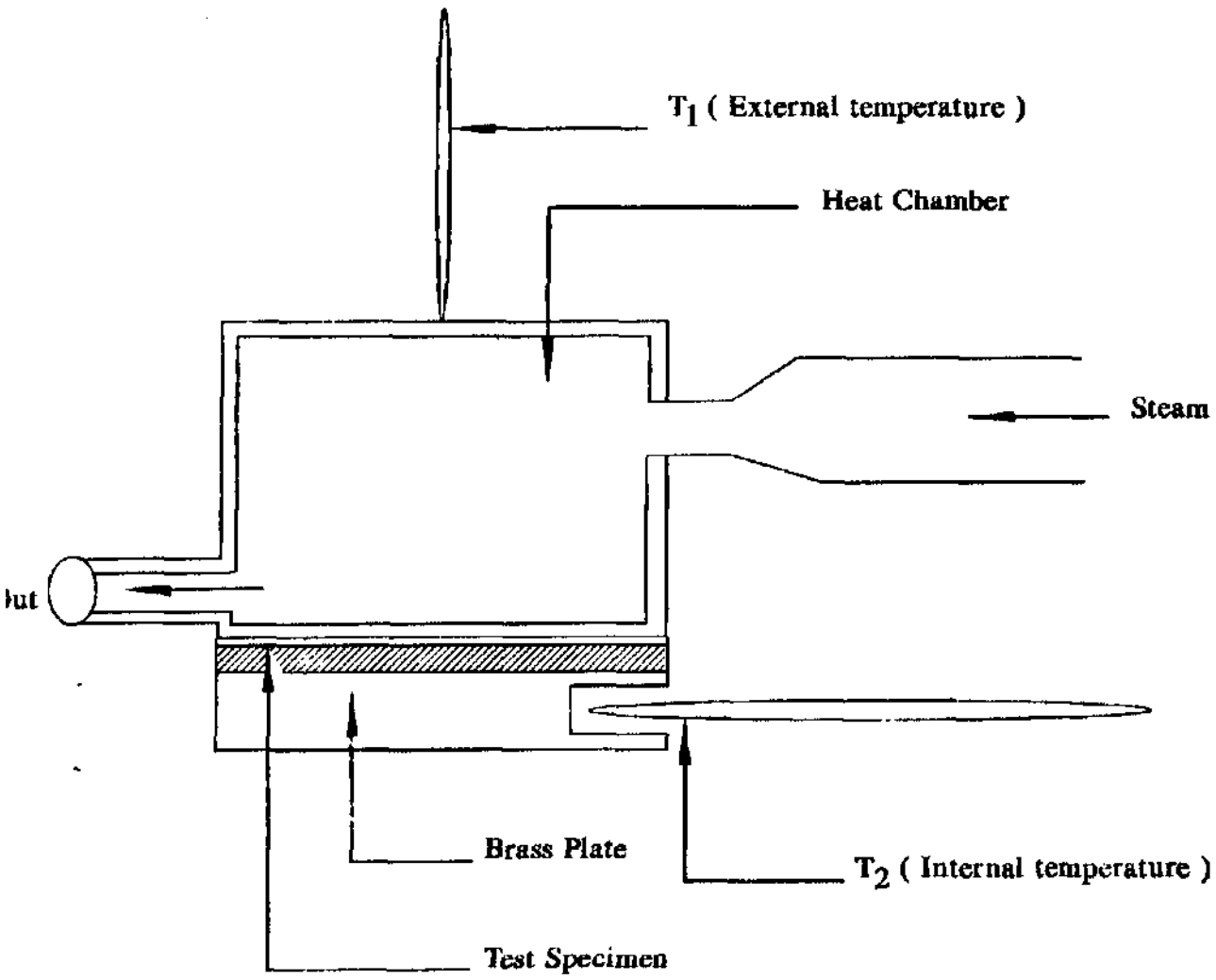


Fig. 38 Conductivity Test Apparatus

Table 3.3 - Thermal Conductivity of Compressed Straw Slabs Produced

SLAB NO	CONDUCTIVITY (K) w/m^{0}C	SLAB NO	CONDUCTIVITY (K) w/m^{0}C
GUM ARABIC		CEMENT	
01	0.027	013	0.012
02	0.037	014	0.018
03	0.030	015	0.020
04	0.025	016	0.015
05	0.036	017	0.010
06	0.029	018	0.022
07	0.034	019	0.020
08	0.036	020	0.021
09	0.040	021	0.023
010	0.049	022	0.028
011	0.050	023	0.037
012	0.051	024	0.020
032	0.020	025	0.076
033	0.020	026	0.021
034	0.042	027	0.019
035	0.028	028	0.034
036	0.035	029	0.031
037	0.038	030	0.035
Average Conductivity = 0.035w/m^{0}C		Average Conductivity = 0.025w/m^{0}C	

3.2.4 BENDING STRENGTH (MODULUS OF RUPTURE) TEST

Specimens of 150mm x 50mm x tmm from each slab sample were tested using the testing apparatus on rollers of 38mm x 38mm diameters kept at a distance of 126mm apart and load applied at the centre. (See fig. 3.3 and plate XII).

A total of 144 tests were carried out on samples of the slab produced. A total of 36 slab samples were produced; - 18 samples from slabs using Gum Arabic as binder and 18 from samples using cement as binder. Each slab sample consists of 4 sample test specimens.

The test specimen is placed on the rollers at a span of 126mm with the centre marked. Using lead balls, load is gradually applied at the centre with the two ends of the test specimen resting on the two rollers with a little over-hang of 25mm at each end. The load was gradually increased until the specimen fails or ruptures.

The failure load was then determined on a scale and the value recorded. Test results were obtained using the following formula as stated in BS 1142 Part I, 1971.

$$S = \frac{3Pl}{2bt^2} \quad \ldots\ldots\ldots\ldots eqn1.$$

where

S = bending strength (Modulus of rupture) N/mm2

P = load at rupture in Newtons (N).

l = span (distance between supports) (mm).

b = width of the test specimen (mm).

t = thickness of the test specimen (mm).

The procedure was then repeated for all the tests specimens and the results obtained are tabulated on table 3.4 Detailed results and calculations are in Appendix IV.



Plate XII - Apparatus for Bending Strength Test

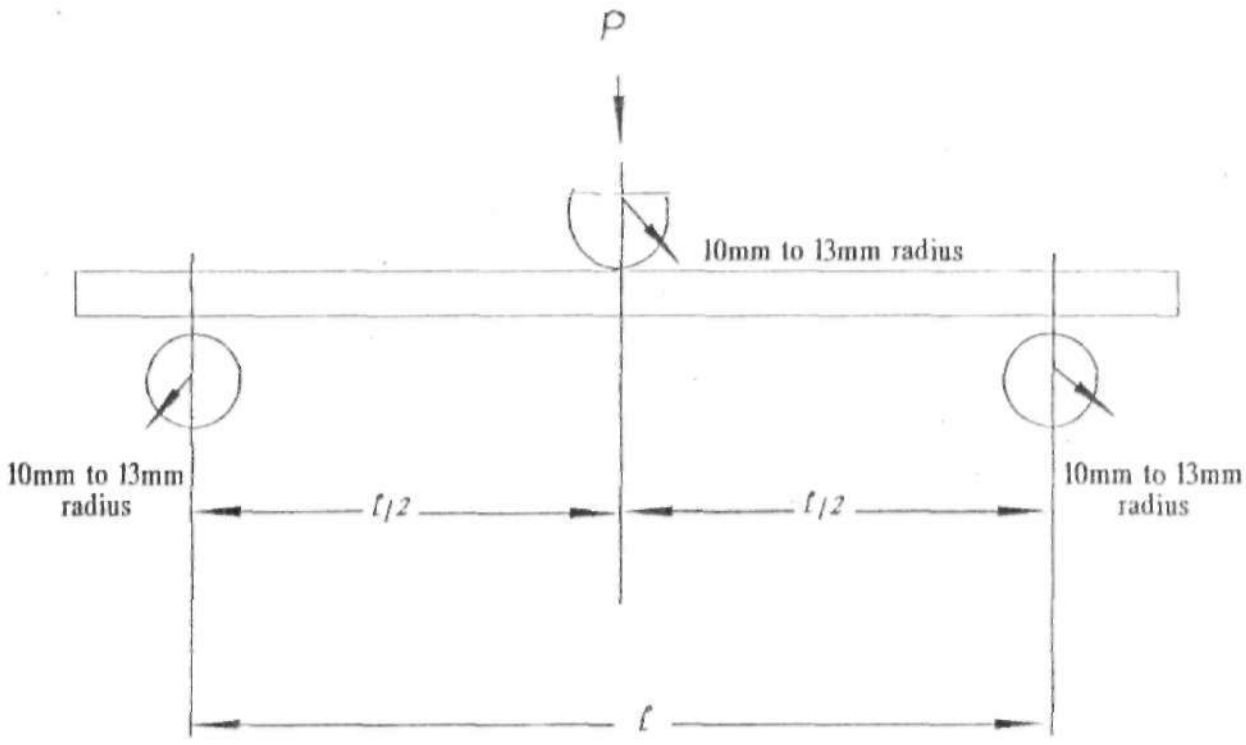


Fig. 39 Application of test for bending strength and deflection

Table 3.4 - Bending Strength (Modulus of Rupture) of Compressed Slabs Produced

SLAB NO	BENDING STRENGTH (N/mm^2)	SLAB NO	BENDING STRENGTH (N/mm^2)
GUM ARABIC		CEMENT	
01	0.25	013	0.23
02	0.30	014	0.26
03	0.29	015	0.28
04	0.28	016	0.25
05	0.29	017	0.20
06	0.24	018	0.303
07	0.30	019	0.28
08	0.48	020	0.28
09	0.33	021	0.32
010	0.38	022	0.33
011	0.45	023	0.35
012	0.55	024	0.37
032	0.183	025	0.25
033	0.28	026	0.28
034	0.25	027	0.275
035	0.46	028	0.37
036	0.33	029	0.35
037	0.35	030	0.38
Average Bending Strength (Modulus of Rupture) = $0.33N/mm^2$		Average Bending Strength (Modulus of Rupture) = $0.29N/mm^2$	

4.0 TEST RESULTS AND DISCUSSIONS

The results of the various tests carried out and described in chapter three are presented and discussed in this chapter. The two types of compressed straw slabs using Gum Arabic and Cement as Binders were compared based on existing standards.

4.1 PHYSICAL AND MECHANICAL PROPERTIES OF THE COMPRESSED STRAW SLAB

4.1.1 DENSITY

The compressed straw slab produced using cement as binder was found to have an average density of 425.53kg/m3 while that produced using Gum Arabic as binder has an average density of 303.17kg/m3. (see table 3.1). These values show that the compressed straw slab produced using cement as binder has a greater density than that produced using Gum Arabic as binder. This is true because, physically, when equal mass/size of both slabs are lifted, the slab with Gum Arabic as binder is lighter. Also, the densities of the binders are different. Cement is denser than Gum Arabic, consequently, slab produced using cement binder was denser.

When compared with values in existing specifications, (BS 4046 Part I & II, 1971), the works of other researchers, both slabs are within range with that using Gum Arabic as binder slightly having lower value.

The code recommends that densities of the straw slabs should be in the range of 330kg/m3 and 440kg/m3. Hermansson (1993) in his work produced similar slabs with densities ranging from 200kg/m3 - 500kgm3.

4.1.2 MOISTURE CONTENT

The average moisture content for the compressed straw slabs using Gum Arabic as binder was found to be 8.61% while that using cement as binder was 5.26%. (see table 3.2). From these values, it shows that the compressed straw slab with Gum Arabic as binder has a higher moisture content than that with cement as binder. This is probably due to the fact that the compressed straw slab with Gum Arabic as binder being less dense has more voids and so can easily absorb moisture from the atmosphere compared with the straw having cement as binder which has a higher density and hence has a lower moisture content probably because of less voids.

Compared with values given in existing standards (BS 4046 Part I & 4 1971), the moisture content values for both straw slabs are within specified range (0% - 20%).

4.1.3 THERMAL CONDUCTIVITY

The average thermal conductivity for the compressed straw slab using Gum Arabic as binder was found to be 0.035w/m°C while that using cement as binder is 0.025w/m°C (see table 3.3).

This results shows no significant difference in conductivity for both type of slabs.

Although there is a 28% increase in conductivity of the slab with Gum Arabic as binder, this can readily be attributed to its high moisture content.

The code (BS 4046, 1971) does not specify any range of conductivities for Building Materials, but it was found that conductivities for similar materials (woodwool) is between 0.075 - 0.125 w/m°C. This shows that the slab produced meets the requirements of the code.

4.1.4 BENDING STRENGTH (Modulus of Rupture)

The compressed straw slabs with cement as a binder has an average bending strength of 0.29N/mm2 while that with Gum Arabic as binder has an average value of 0.33N/mm2. (see table 3.4). This shows that the straw slab with Gum Arabic binder has a higher ability to support load before failure compared with the straw slab using cement as binder. This variation which is about 12% can be attributed to the fact that cement does not readily bond with rice straw due to the high percentage content of carbohydrate which has to be thoroughly removed from the straw before mixing with cement. This assertion is further supported with the fact that during cutting of the slabs into test specimens, considerable quantity of unreacted cement pulled off.

F. A. O. S.: 1963 specify that bending strength for similar materials of density 300 - 400 kg/m3 should be in the range of 1.0 - 7.5 N/mm2. This shows that the values got from this study is below standard as regards particle boards of low density.

4.2 RELATIONSHIPS BETWEEN PROPERTIES MEASURED

Properties of the compressed straw slabs produced such as density, moisture content, thermal conductivity and bending strength were compared in order to determine their relationship and influence on the straw slabs.

Owing to the compressed straw slab industry's recent origin, only a few standards as yet exist for it. These standards only specify minimum and maximum values of a particular property of the slab.

The British Standard Institute (B.S.I.) is yet to establish a standard that correlates one property of the slab with another.

The standard used for correlation in this study is taken from "Plywood and other wood based panels" by the F. A. O. (29). This will be referred to in this study as F. A. O. S:1963. (It is the report of an International Consultation on plywood and other wood-based panel products held in Rome, 8 - 19 July, 1963). The standard is based mainly on experience in the use of flax sheaves for the production of this type of board.

It was adopted because this type of low density board has similar properties with compressed straw slabs. For example, ranges of thickness and density is the same, mode of production is the same too and the report is International. Table 3.5 below is the F. A. O. S: 1963 standard.

IBRARY

Table 3.5 - F. A. O. S: PLYWOOD AND OTHER WOOD BASED STANDARDS:

PROPERTY OF BOARD	UNIT	F. A. O. S: 1963
Density	Kg/m^3	300 - 400
Thickness	mm	16 - 50
Bending Strength	N/mm^2	1 - 7.5
Tensile Strength	N/mm^2	0.1 - 0.3
Moisture Content	%	10 - 12
Thermal Conductivity	w/m^0C	0.06 - 0.071
Deflection	mm	4 Max

Source:- F.A.O. Publications (Report of an International Consultation on plywood and other wood-based panel products held in Rome, 8 - 19 July, 1963).

4.2.1 THERMAL CONDUCTIVITY AND DENSITY

A graph of thermal conductivity against density for both type of slab was plotted. (See fig. 3.1 and 3.2). The result for both slabs show an increase in conductivity as density increases. For the slab with Gum Arabic as binder, a maximum density of $440Kg/m^3$ has a corresponding thermal conductivity of $0.065w/m^0C$ while a minimum density of 330Kg/m3 gives a conductivity of 0.041w/m°C.

Also, for the cement straw slab, a maximum density of 440Kg/m3 gives a thermal conductivity λ of 0.05w/m°C and a minimum density given a value of $0.3N/m^0C$.

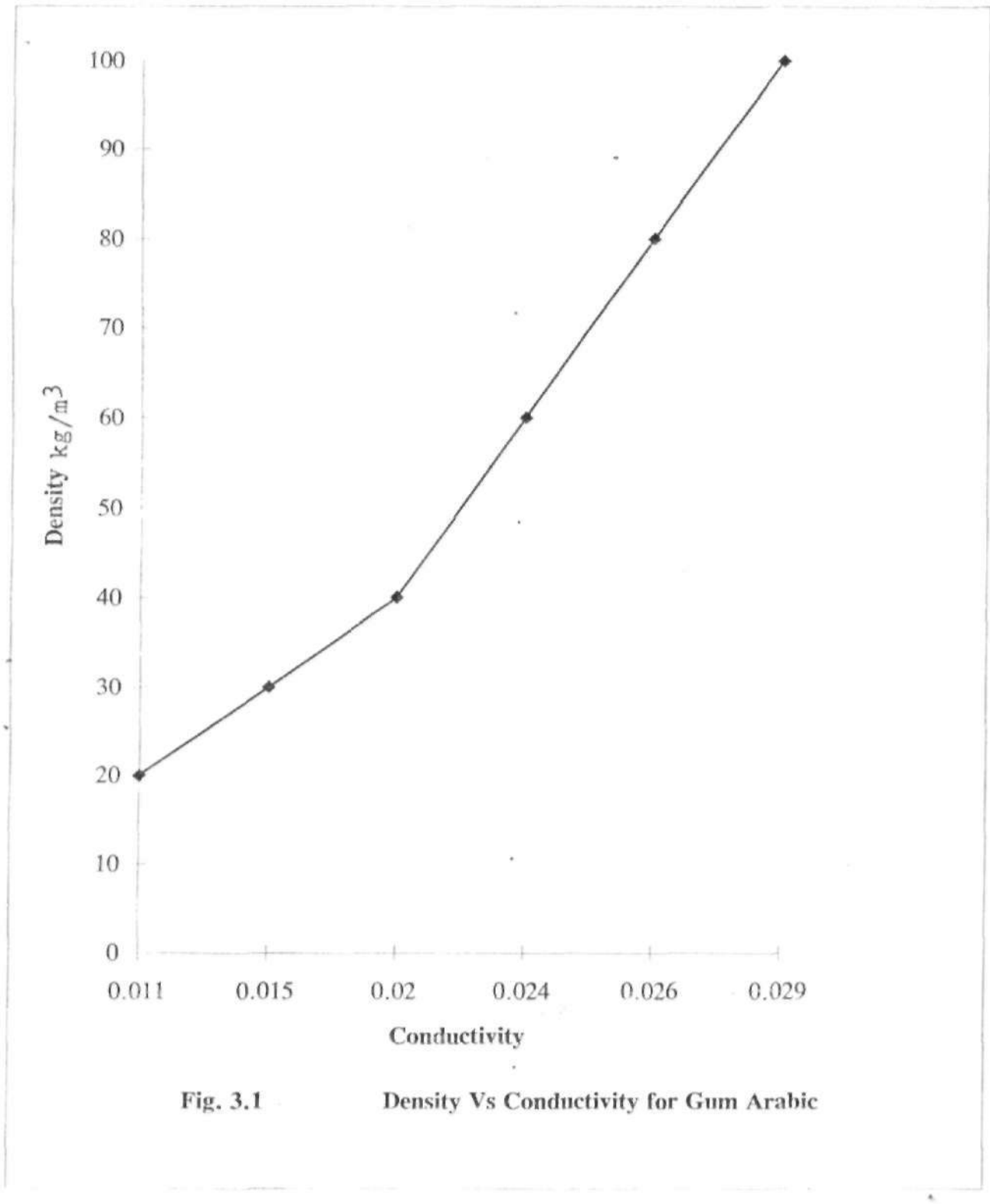


Fig. 3.1 Density Vs Conductivity for Gum Arabic

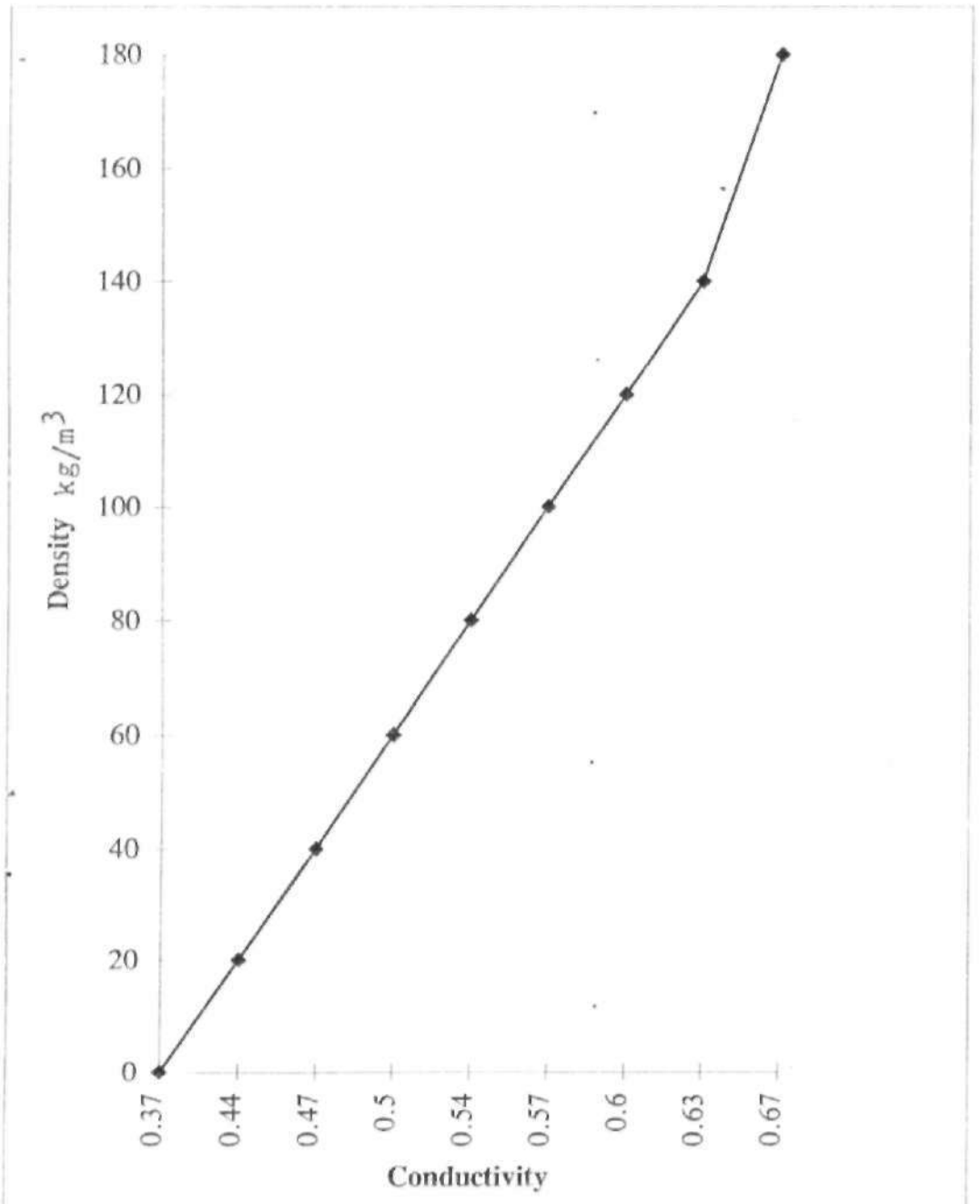


Fig. 3.2 **Density Vs Conductivity for Cement**

These values meet standard specifications. F.A.O.S: 1963 specify that thermal conductivity for a board of 300 - 400 Kg/m3 density should be between 0.06 - 0.071 w/m°C.

This shows that the slab produced satisfy the requirement as regards density and conductivity.

4.2.2 THERMAL CONDUCTIVITY AND MOISTURE CONTENT

A graph of thermal conductivity against moisture content for both slabs plotted show a significant increase in conductivity as moisture content increases. (see fig. 3.3 and 3.4 respectively).

For Gum Arabic straw slab with a maximum moisture content of 12% gives a conductivity of 0.072 w/m°C and for a minimum moisture content of 10%, gives a corresponding thermal conductivity 0.05 w/m°C. For the straw slab with cement as binder, a maximum moisture content of 12% has a thermal conductivity of 0.09 w/m°C and a minimum moisture content of 10% has a conductivity of 0.073w/m°C. These results agrees with table 3.5 (F.A.O.S: 1963) showing the slab produced is satisfactory as regards moisture content and conductivity.

4.2.3 BENDING STRENGTH (Modulus of Rupture) AND DENSITY

Figures 3.5 and 3.6 show relationship between bending strength (Modulus of rupture) and density for both types of slab.

For the straw with Gum Arabic as binder, a maximum density of 440Kg/m3 has a bending strength of 0.62N/mm2 and for a minimum density of 330Kg/m3 has a bending strength of 0.39N/mm2.

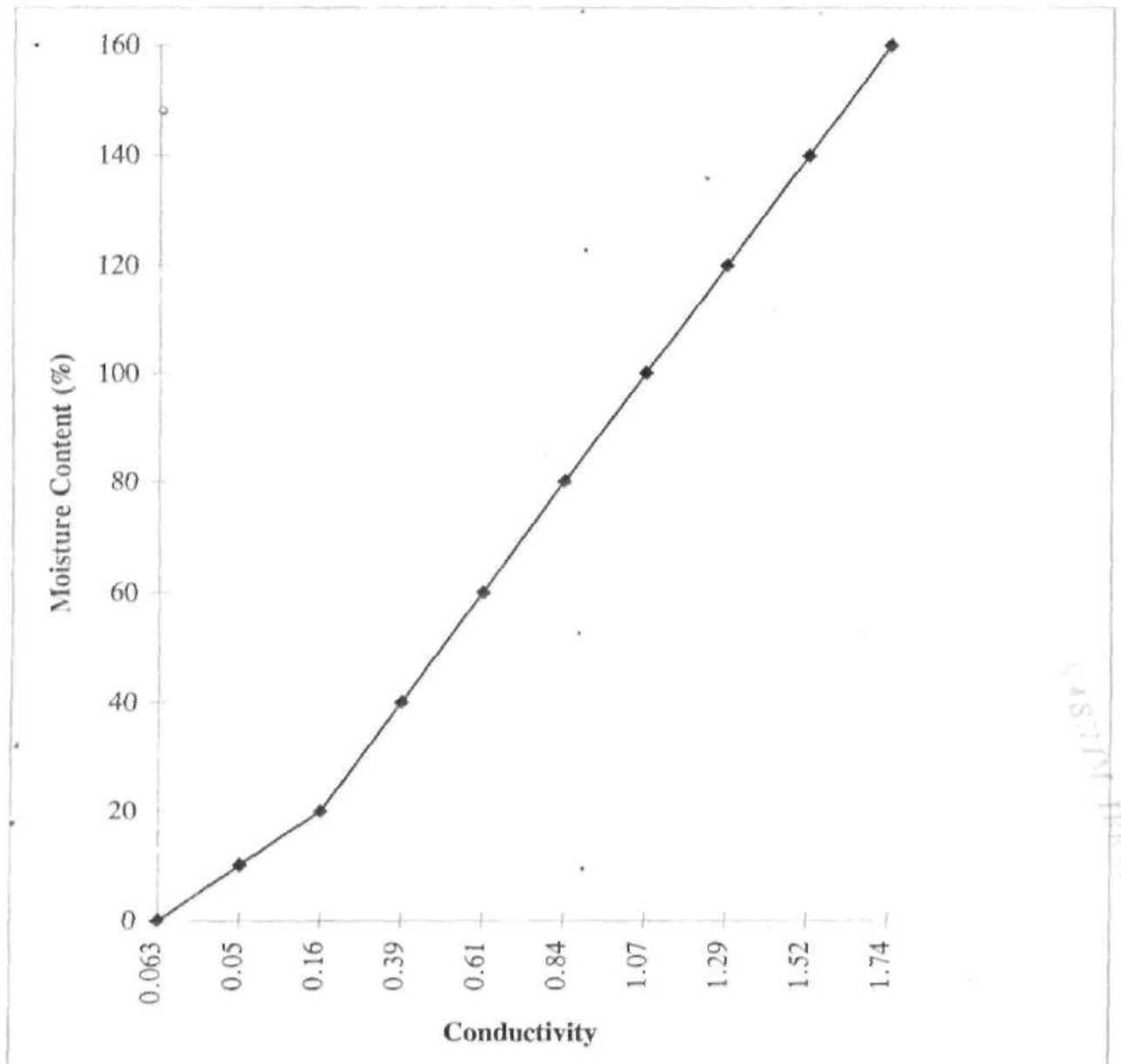


Fig. 3.3 Moisture Content Vs Conductivity for Gum Arabic

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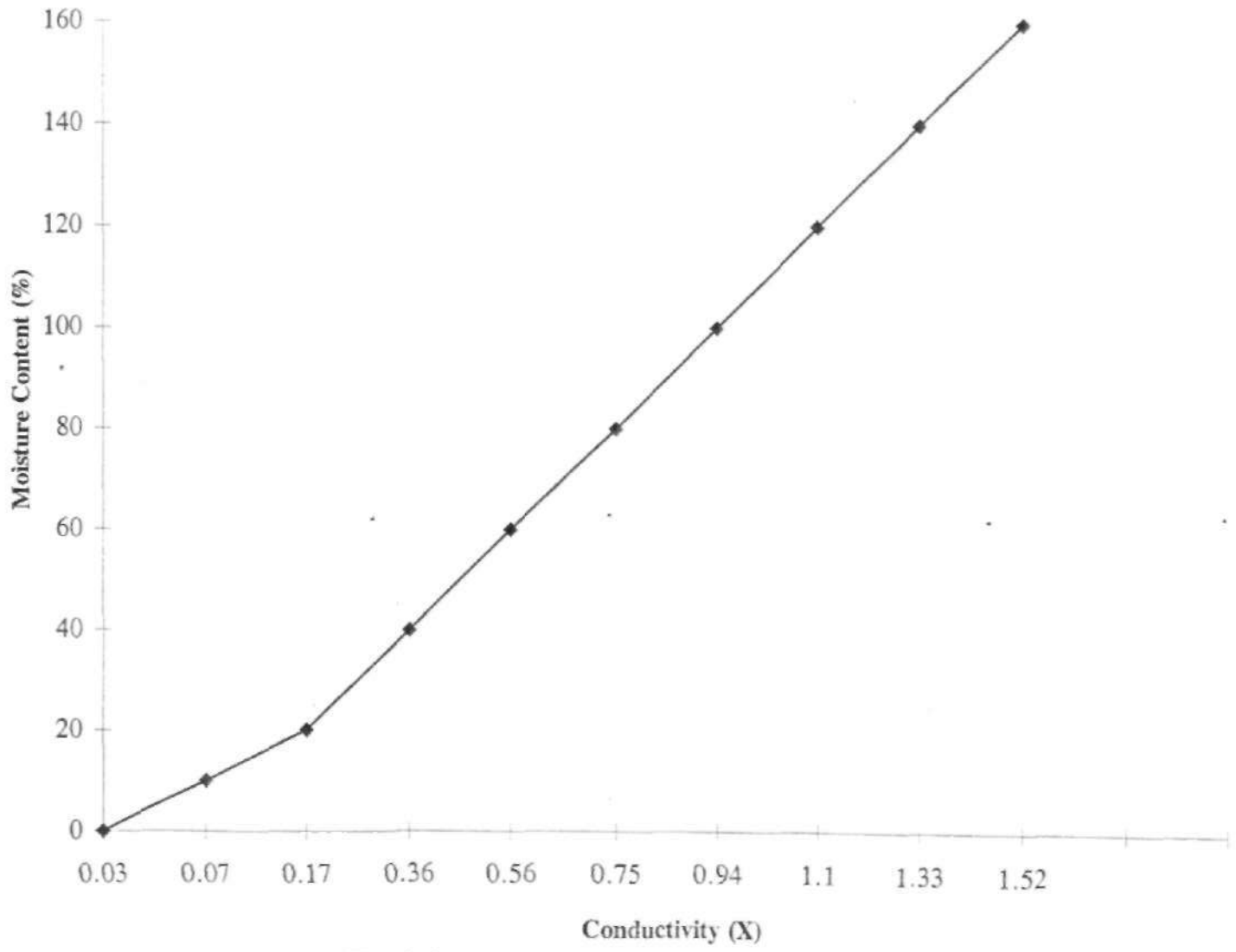


Fig. 3.4 moisture content vs Conductivity for Cement.

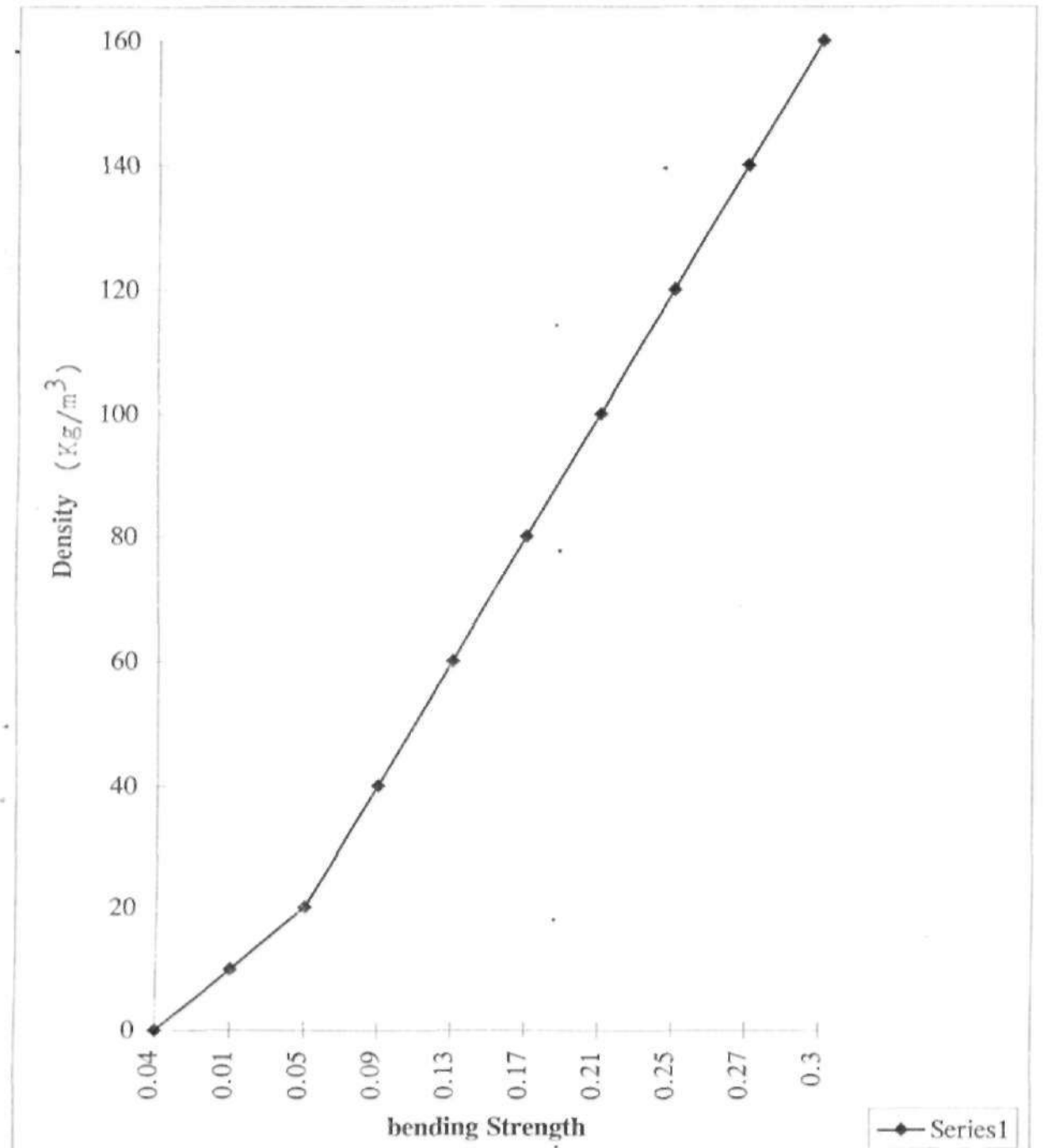


Fig. 3.5 **density Vs Beding Strength for Gum Arabic**

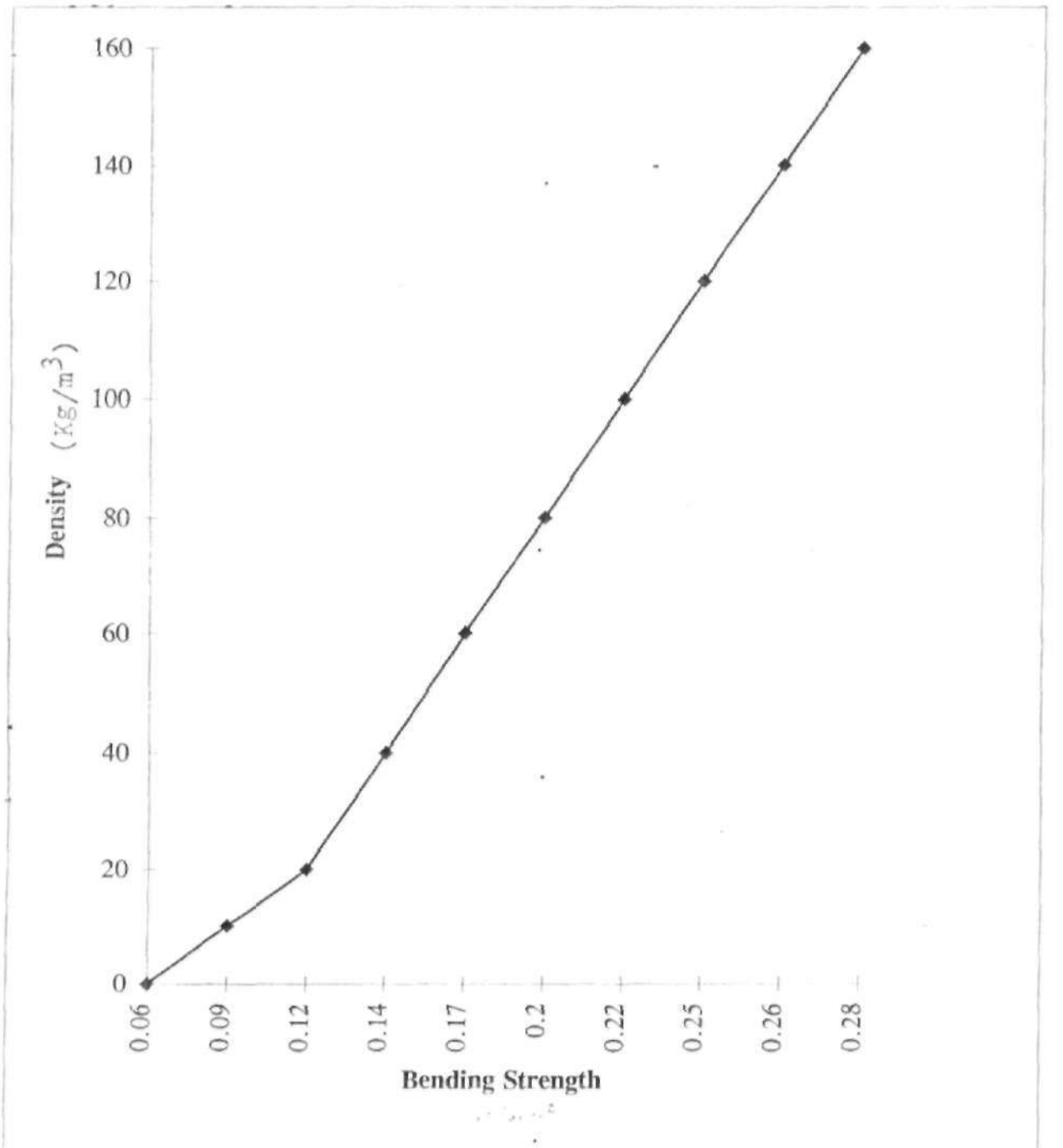


Fig. 3.6 Graph of density Vs Beding Strength for Cement

For the straw slab with cement as binder, a maximum density of 440Kg/m3 has a bending strength of 0.32N/mm2 and a minimum density of 330Kg/m3 has a bending strength of 0.20N/mm2. Values got from literature for similar materials are between 0.25N/mm2 - 0.46N/mm2 for the same range of densities (Hermansson, 1993).

Compared with table 3.5 (F.A.O.S: 1963) standard, the result is below the specification.

This is not unconnected with some factors militating on the study. For example, the technology of producing straw slabs is more of a dry season technology than that of a rainy season. During the production of the slabs which took place during the rainy season, it took time to dry and proper curing was difficult. Also, the pressing machine used has a capacity of 0.1344N/mm2. It should also be noted that from the comparisons made, mode of production of the slab is not the same. the binders used are also not the same.

4.3 COMPARISON BETWEEN COMPRESSED STRAW SLAB WITH GUM ARABIC AS BINDER AND THAT WITH CEMENT AS BINDER

It is necessary to compare the two types of slab produced in terms of their properties and then relate their values to the ones in existing codes so as to determine their suitability or otherwise.

4.3.1 DENSITY

In terms of density, the compressed straw slab with cement as

binder has a higher density (425Kg/m3) than that produced with Gum Arabic as binder (303.17Kg/m3) as can be seen on table 3.1.

This high density is expected to have enhanced bending strength but for the poor bonding between the straw and cement. The high density give rise to more weight of the slab and most insulating materials are known to be of light weight hence not quite economical though still within specifications.

4.3.2 MOISTURE CONTENT

When both slabs are compared in terms of moisture content, the straw slab with Gum Arabic as binder has a higher moisture content (8.61%). This leads to a rise in conductivity compared to that of cement straw slab, consequently, cement straw slab has a better thermal conductivity. The high moisture content implies that there are more voids which leads to a reduction in strength; but this has been compensated by the strong bond between the Gum Arabic and the straw.

4.3.3 THERMAL CONDUCTIVITY

In terms of thermal conductivity, cement straw slab has a lower conductivity than Gum Arabic straw slab and thus has a better conductivity. This is because of less voids and thermal conductivities of its components (straw & cement).

4.3.4 BENDING STRENGTH

The Gum Arabic straw slab has a greater ability to support load than the cement straw slab. Though a non-structural element, it should have a resistance that would at least withstand its self-weight when in service. This has been achieved by both type of slabs.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

After a critical analysis and discussions on the various tests performed on the compressed rice straw slabs, similar building components, specifications in existing codes and based on this study, the following conclusions were drawn:

(1) Rice straw is suitable in the production of compressed straw slabs.

(2) A locally fabricated pressing machine (like the one proposed by the author) can be used in the production of compressed straw slabs.

(3) Compressed straw slabs produced using the locally fabricated pressing machine though of low bending strength can still be useful as a building material; e.g thermal and sound insulating boards.

5.2 RECOMMENDATIONS

Within the limits of this study, it is recommended that:

(1) Further investigations should be carried out to determine the performance of the slab in service.

(2) Investigation should be carried out on how to improve the efficiency and output of the local pressing machine with a view to simplification and more affordability.

(3) Tests should be carried out to determine the characteristics

of the slab when the straw flakes are arranged in a definite pattern.

Within the premises of this study, both types of straw slabs produced are recommended for use (after further tests has been carried out on them) as non - structural elements.

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APPENDIX I

SAMPLE CALCULATIONS OF DENSITY FOR COMPRESSED STRAW SLABS PRODUCED

BINDER - GUM ARABIC.

SLAB NO. 01

Mass of test specimen = 258 g = 0.258 kg

Length of " " = 450 mm = 0.45 m

Width " " " = 320 mm = 0.32 m

Thickness of " " = 85 mm = 0.0085 m

Density = M_1/V_1 = (0.258/0.001224) = 211.78Kg/m^3

Mass of test specimen = 269g = 0.269kg

Length of " " = 485mm = 0.485m

Width " " " = 300mm = 0.30m

Thickness of " " = 8.4mm = 0.0084m

Density = (0.269/0.001222) = 220Kg/m^3

Mass of test specimen = 267 g = 0.267 kg

Length of " " = 475 mm = 0.475 m

Width " " " = 310 mm = 0.310 m

Thickness of " " = 8.42 mm = 0.00842 m

Density = M/V = 0.207/0.001240 = 215.55Kg/m^3

Average density for slab No 01

= (211.15 + 220 + 215.55)/3 = (646.71)/3 = 215.56Kg/m^3

SLAB NO. 02.

Mass of test specimen = 46 g = 0.046 kg

Length of " " = 210 mm = 0.210 m

Width " " " = 80 mm = 0.080 m

Thickness of " " = 8.2 mm = 0.0082 m

Density = Mass/Vol = (0.046)/(0.0001377) = 335.14Kg/m^3

Mass of test specimen = 30 g = 0.03 kg

Length of " " = 130 mm = 0.130 m

Width " " " = 80 mm = 0.080 m

Thickness of " " = 8.4 mm = 0.0084 m

Density = Mass/Vol = (0.03)/(0.0000873) = 333.33Kg/m^3

Mass of test specimen = 20.9 g = 0.0209 kg

Length of " " = 80 mm = 0.08 m

Width " " " = 75 mm = 0.075 m

Thickness of " " = 8.5 mm = 0.0085 m

Density =

Average density for slab No. 02

= (335.14 + 333.33 + 330)/3 = 332.82Kg/m^3

Similar calculations were done for the remaining slabs.

BINDER - CEMENT

SLAB NO. 013

Mass of test specimen = 85 g = 0.085 kg

Length of " " = 195 mm = 0.195 m

Width " " " = 133 mm = 0.133 m

Thickness of " " = 8 mm = 0.008 m

Density = = 404.76 Kg/m3

Mass of test specimen = 31 g = 0.031 kg

Length of " " = 132 mm = 0.132 m

Width " " " = 81 mm = 0.081 m

Thickness of " " = 8.5 mm = 0.0085 m

Density = (0.031/0.000091) = 340.66 Kg/m3

Mass of test specimen = 50 g = 0.050 kg

Length of " " = 132 mm = 0.132 m

Width " " " = 112 mm = 0.112 m

Thickness of " " = 8.2 mm = 0.0082 m

Density = (0.050/0.000120) = 416.67 Kg/m3

Average density for slab No. 013

= (404.76 + 340.66 + 416.67)/3 = 387.36Kg/m^3

SLAB NO. 014

Mass of test specimen = 44 g = 0.044 kg

Length of " " = 135 mm = 0.135 m

Width " " " = 63 mm = 0.063 m

Thickness of " " = 12.5 mm = 0.0125 m

Density = (0.044/0.00011) = 400Kg/m^3

Mass of test specimen = 84 g = 0.084 kg

Length of " " = 135 mm = 0.135 m

Width " " " = 130 mm = 0.130 m

Thickness of " " = 12.3 mm = 0.0123 m

Density = (0.084/0.00022) = 381.82Kg/m^3

Mass of test specimen = 75 g = 0.075 kg

Length of " " = 132 mm = 0.132 m

Width " " " = 113 mm = 0.113 m

Thickness of " " = 12.5 mm = 0.0125 m

Density = (0.075/0.00019) = 394.74Kg/m^3

Average density for slab No. 014

= (400 + 381.82 + 394.74)/3 = 392.19Kg/m^3

N.B. Similar calculations were carried out for the remaining slabs.

APPENDIX II

SAMPLE CALCULATIONS FOR MOISTURE CONTENT FOR THE COMPRESSED STRAW SLABS PRODUCED

SLAB NO. 01. BINDER - GUM ARABIC

Moisture Content $M = (W_1 - W_0)/W_1 \times 100$

where

W1 = Mass of test specimen

W0 = " " " oven dried.

For slab No 01

W1 = 106 g

W0 = 100 g

M = (106 - 100)/100 x 100 = 6.0%

W1 = 107.4 g

W0 = 101.5 g

M = (107.4 - 101.5)/101.5 x 100 = 5.8%

W1 = 110 g

W0 = 103.5 g

M = (110 - 103.5)/103.5 x 100 = 6.3%

Average Moisture Content

= (6.0 + 5.8 + 6.3)/3 = 6.03%

SLAB NO 02

W1 = 160 g

WO = 146.5 g

M = (160 - 146.5)/146.5 x 100 = 9.21%

W1 = 158 g

WO = 145 g

M = (158 - 145)/145 x 100 = 8.97%

W1 = 153 g

WO = 140.5 g

M = (153 - 140.5)/140.5 x 100 = 8.9%

Average Moisture Content

= (9.21 + 8.97 + 8.9)/3 = 9.1%

BINDER - CEMENT

SLAB NO 013

W1 = 84.9 g

WO = 83.8 g

M = (84.9 - 83.8)/83.8 x 100 = 1.3%

W1 = 83 g

WO = 82 g

M = (83 - 82)/82 x 100 = 1.22%

W1 = 89 g

W0 = 88 g

M = (89 - 88)/88 x 100 = 1.1%

Average Moisture Content = (1.3 + 1.22 + 1.1)/3 = 1.22%

N.B. Similar calculations were carried out on the remaining slabs.

SLAB 014

W1 = 78 g

W0 = 76 g

M = (78 - 76)/76 x 100 = 2.6%

W1 = 90 g

W0 = 88 g

M = (90 - 88)/88 x 100 = 2.3%

W1 = 82 g

W0 = 80 g

M = (82 - 80)/80 x 100 = 2.5%

Average Moisture Content

= (2.6 + 2.3 + 2.5)/3 = 2.5

APPENDIX III

THERMAL CONDUCTIVITY (λ) TEST: DETAILS AND SAMPLE CALCULATIONS

DEFINITIONS

(1) Heat Capacity:- J/°C

This is the amount of heat required to raise the temperature of a body by 1°C.

(2) Specific Heat Capacity:- (J/Kg°C)

This is the amount of heat required to raise the temperature of a unit mass of a body by 1°C.

(3) N.B. For Brass, specific heat capacity C = 0.38 x 103 JKg-1K-1

N.B. Degree Kelvin K = (273 + θ) °C

THEORY

Heat normally flows from a higher level (temp.) to a lower level (temp.); hence heat flows either from the external environment (outside a building) to the internal environment (inside a building) or vice versa. The fabric of the building can then be considered as functioning as a filter or barrier between the external and internal environment.

Apart from determining the thermal conductivity of the compressed straw slab, the test specimen was also studied to determine how it behaves in relation to the flow of heat and moisture.

Thermal Conductivity (λ) :- This is defined as "the rate of heat passage across a material per unit area per °C difference between faces for 1 meter thickness of the material".

Consider an element under steady - state conditions such that the temperature difference $t_2 - t_1$ between the two faces is constant. Let the area of the element be A mm^2 and its thickness be t mm. (See diagram below).

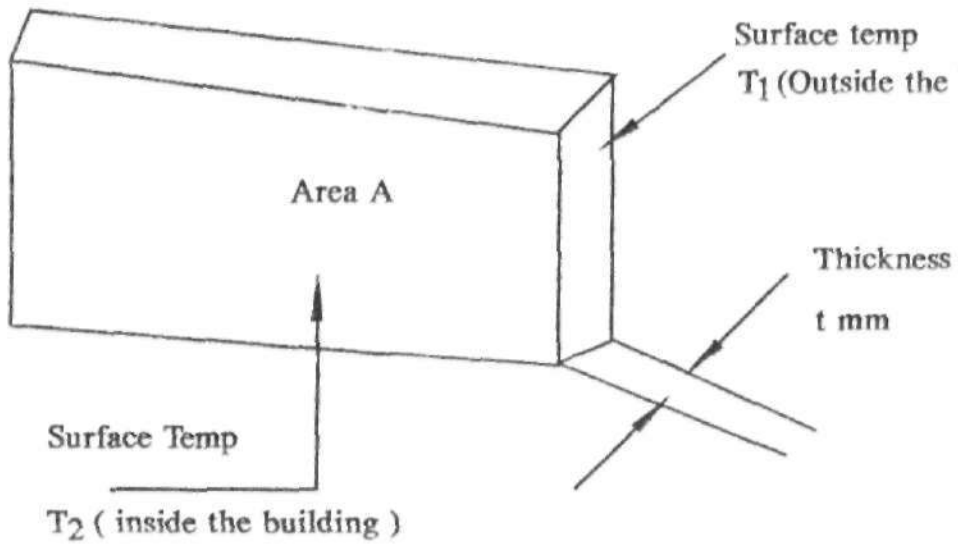


Fig. 3.7 - Application of Principles for Conductivity test.

If Q = rate of heat flow between the two surfaces in Watts, then:

Q varies directly as the temperature difference, ($T_2 - T_1$)

Q varies directly as the area, A (mm^2),

Q varies inversely as the thickness, t (mm).

Hence $Q = (KA)/t \ (T_1 - T_2)$ Watts — (1)

Where K is a constant called the thermal conductivity of the material.

$$Q = (KA)/t \ (T_1 - T_2) \ WM^{-1} K^{-1} - (2)$$

PROCEDURE: The apparatus used to measure the thermal conductivity of the test specimen is the lees Disc (Plate 3.2).

This consists of a cylindrical/Rectangular hollow metal steam chamber through which steam is passed from a steam generator. The solid bottom has a long boring in the side to take a thermometer. The steam chamber rests on the trial disc of the same diameter. which in turn rests on a solid metal circular/Rectangular block, with boring for thermometer. This is suspended on strings in mid-air. (See Plate 3.3, fig. 3.7).

Steam is passed through until the temperatures of the upper and lower thermometers are steady, a process that may take half (1/2) an hour. Let the temperatures of the upper and lower thermometers representing outside and inside buildings be T1 and T2. Find the mass of the solid metal circular block before or after the experiment and find its specific heat capacity. Measure the diameter and thickness of the disc (compressed straw slab) using a micrometer screw gauge or a vernier Calliper.

Then, set up the apparatus and pass stream through until T1 and T2 are steady, and then read the temperatures.

Take off the steam chamber, leaving the disc. With a tiny bunsen flame under the centre of the lower block, warm it up about 5 - 10°C from T2. Remove the bunsen burner. With stop clock ready, start timing and reading at about T2 + 5. Read every half minute until T2 - 5°C is reached.

Plot a graph of temperature (vertically) against time (horizontally), choosing suitable scales to obtain good cooling

curve. Draw the tangent at T2 and calculate its gradient, $d\theta/dt$ in °C/sec. This will now enable you to calculate the Rate of emission of heat, (same as rate of heat flow Q) Q1 from the relation:

$$Q_1 = MC\ (d\theta/dt) \text{ ---------- } (3)$$

where m = mass of block

c = specific heat capacity of block (can be got from table 3.6)

$d\theta/dt$ = gradient (rate of cooling or fall of temperature.

With Q1 (which is equal to Q) found from equation (3).

(thermal conductivity) can now be found from equation (2).

DETAIL CALCULATIONS

BINDER - GUM ARABIC

SLAB NO. 01.

Length of test specimen = 145 mm; c = 380 J/Kg°C.

Width " " = 130 mm; m = 462 g = 0.462 Kg.

Thickness t of test specimen = 8.4 mm

T1 = External temperature = 64°C

T2 = Internal " = 34.5°C

From cooling curve graph (temp. Vs time)

gradient = AB/BC = $d\theta/dt$ = (42.0 - 34.5)/12.4 - 0

= 7.5/12.4 = 0.010

$d\theta/dt$ = 0.010

Apply formula:

$Q_1 = MC\ (d\theta/dt) = 0.0462 \times 380 \times 0.010$

$= 1.77$ Joules

$Q_1 = 1.77$ Joules.

Apply formula:

$$Q_1 = KA\ (T_1 - T_2)/t$$

$$K = (Q_1 \times t)/A(T_1 - T_2)$$

$K = (177 \times 0.0084)/0.558 = 0.027 W/M^0C$

$= 0.027$ w/m°C. ■ $K = 0.027$ w/m°C.

Thermal Conductivity (K) for slab No. 01

$= 0.027$ w/m°C

Table 3.6 - Specific Heat Capacities

Substance	Specific Heat $JKg^{-1}K^{-1}$	Substance	Specific Heat $JKg^{-1}K^{-1}$
Aluminium	0.91×10^3	Ice	2.1×10^3
Brass	0.38	Paraffin wax	2.9
Copper	0.39	Quartz	0.7
Iron	0.47	Rubber	1.7
Lead	0.13	Stone	0.9
Mercury	0.14	Wood	1.7
Nickel	0.46	Alchohol	2.5
Platinum	0.13	Brine (25% by wt)	3.4
Silver	0.24	Carbon Tetrachloride	0.84
Solder	0.18	Ether	2.4
Steel	0.45	Glycerine	2.5
Ebonite	1.7	Paraffin oil	2.1
Glass	0.7	Turpentine	1.76

Source:

NELKON & PARKER, Advanced Level Physics, 3rd Edition, Pg 199.

DETAILED CALCULATIONS

Binder - Gum Arabic.

Slab No. 01

Length of test specimen = 145mm; C = 350 J/Kg ℃

Width of test specimen = 130mm M = 462 g = 0.462kg

Thickness of test specimen = 8.4mm

T_1 = External temperature = 64℃

T_2 = Internal temperature = 34.5℃

DATA FOR COOLING CURVE:

Time (Mins)	Temp (℃)	Time (Mins)	Temp(℃)	Time (Mins)	Temp(℃)
0	45	10.5	35.2	21.0	31
0.5	44	11.0	35.1	21.5	31
1.0	43.50	11.5	35.0	22.0	30.9
1.5	42.80	12.0	34.8	22.5	30.6
2.0	42.4	12.5	34.3	23.0	30.3
2.5	41.9	13.0	34.1	23.5	30.2
3.0	41.4	13.5	34.0	24.0	30.1
3.5	41.0	14.0	33.8	24.5	30
4.0	40.5	14.5	33.2	25.0	30
4.5	40.0	15.0	35.1	25.5	30
5.0	39.5	15.5	33.0		
5.5	39.1	16.0	32.9		
6.0	38.6	16.5	32.8		
6.5	38.2	17.0	32.5		
7.0	38.0	17.5	32.1		
7.5	37.6	18.0	32.0		
8.0	37.1	18.5	31.9		
85	36.9	19.0	31.8		
9.0	36.5	19.5	31.6		
9.5	36.1	20.0	31.4		
10.0	35.8	20.5	31.1		

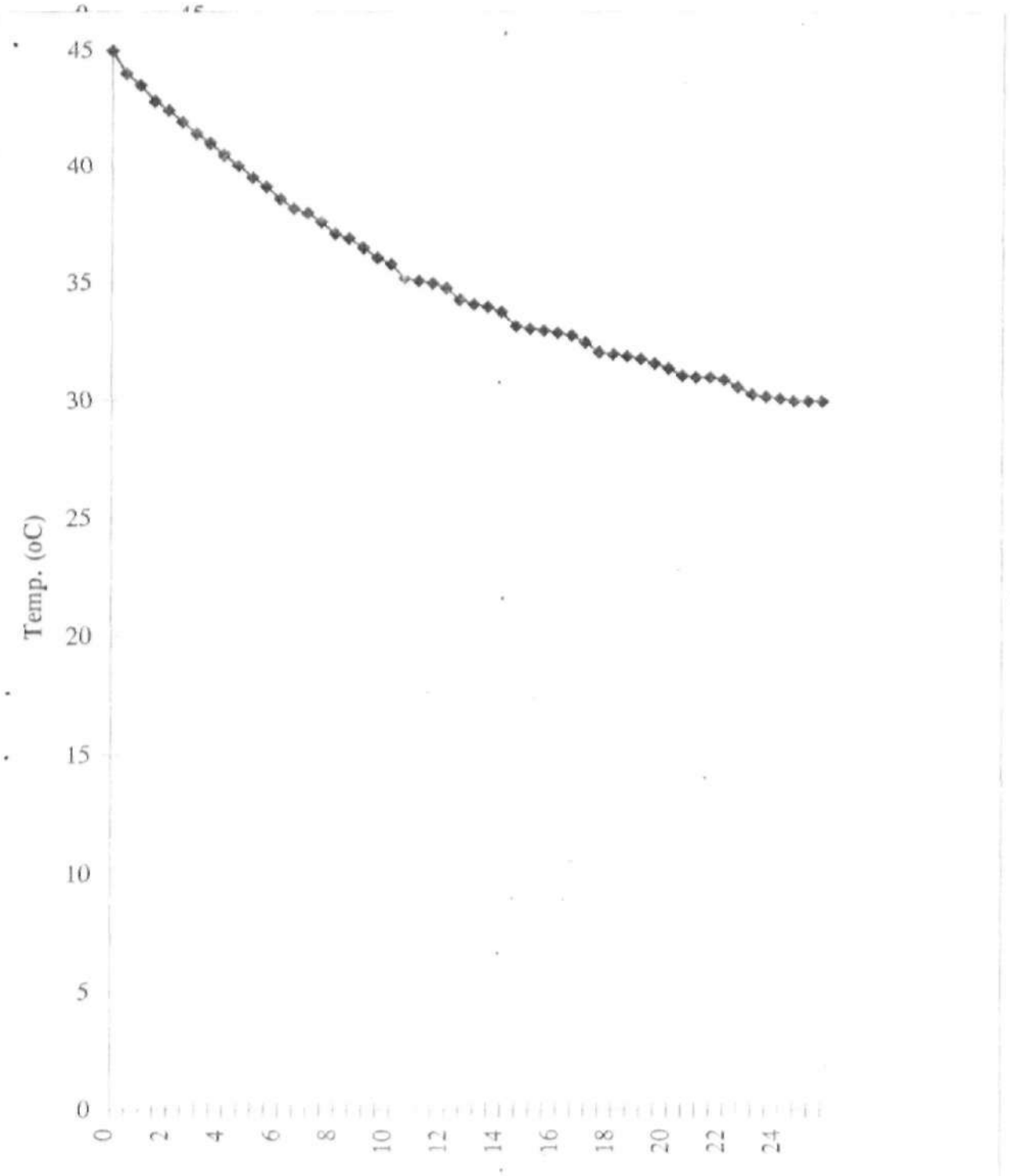


Fig. 4.0 Temp. Vs Time (Cooling Curve)

APPENDIX IV

SAMPLE CALCULATIONS OF BENDING STRENGTH (Modulus of Rupture) FOR COMPRESSED STRAW SLABS PRODUCED

As already stated, from B.S. 1142: Part I: 1971, the Bending strength (Modulus of rupture) S is given by the formula:

$$S = (3PL)/2bt^2$$

where P = failure load

l = span of test specimen

b = width of test specimen

t = thickness of test specimen.

SLAB NO. 01; BINDER - GUM ARABIC.

Slab 01_1

P = 0.395 Kg = 3.95 N

b = 45.9 mm

t = 8.4 mm

$S = (3PL)/2bt^2 = (3 \times 3.95 \times 126)/2 \times 45.9 \times 8.4^2$

$= 0.23\ N/mm^2$

Slab 01_2

b = 45.8 mm

t = 8.5 mm

P = 0.45 Kg

= 4.6 N

$S = (3 \times 4.6 \times 126)/2 \times 45.8 \times 8.4^2$

$= 0.27 N/mm^2$

Slab 01_3

b = 45.8 mm

t = 8.4 mm

P = 0.46 Kg

= 4.5 N

$S = (3 \times 4.6 \times 126)/2 \times 45.8 \times 8.4^2$

$= 0.27 N/mm^2$

Slab 01_4

b = 45 mm

t = 8.5 mm

P = 0.42 Kg = 4.2 N

$S = (3 \times 4.2 \times 126)/2 \times 45.8 \times 8.5^2$

$= 0.24 N/mm^2$

Average = $(0.23 + 0.26 + 0.27 + 0.24)/4 = 0.25 N/mm^2$

SLAB NO. 02_1

b = 49.5 mm

t = 7.8 mm

P = 0.52 Kg

$S = (3 \times 5.2 \times 126)/2 \times 49.5 \times 7.8^2$

$= 0.24 N/mm^2$

SLAB NO. 02_2

b = 50.0 mm

t = 8 mm

P = 0.50 Kg

$S = (3 \times 5 \times 126)/2 \times 50 \times 8^2$

$= 0.30 N/mm^2$

SLAB NO. 02_3

b = 49.0 mm

t = 8 mm

P = 0.48 Kg

$S = (3 \times 4.8 \times 126)/2 \times 49 \times 8^2$

$= 0.29 N/mm^2$

SLAB NO. 02_4

b = 50 mm

t = 8 mm

P = 0.49 Kg

$S = (3 \times 4.9 \times 126)/2 \times 50 \times 8^2$

$= 0.29 N/mm^2$

Average bending strength for slab No. 02

$= (0.33 + 0.30 + 0.29 + 0.29)/4 = 0.30 N/mm^2$

BINDER - CEMENT

SLAB NO. 03_1

b = 44.9 mm

t = 7.8 mm

P = 0.35 Kg

= 3.5 N

$S = (3 \times 3.5 \times 126)/2 \times 44 \times 7.8^2$

$= 0.24 N/mm^2$

SLAB NO. 03_2

b = 50 mm

t = 8 mm

P = 0.36 Kg

= 3.6 N

$S = (3 \times 3.6 \times 126)/2 \times 50 \times 8^2$

$= 0.21 N/mm^2$

SLAB NO. 013_3

b = 50 mm

t = 8 mm

P = 0.37 Kg

= 3.7 N

$S = (3 \times 3.7 \times 126)/2 \times 50 \times 8^2$

$= 0.22 N/mm^2$

SLAB NO. 013_4

b = 50 mm

t = 8 mm

P = 0.38 Kg

= 3.8 N

$S = (3 \times 3.8 \times 126)/2 \times 50 \times 8^2$

$= 0.23 N/mm^2$

Average = $(0.33 + 0.30 + 0.29 + 0.29)/4 = 0.30 N/mm^2$

SLAB NO. 014_1

b = 49.5 mm

t = 12.5 mm

P = 1.00 Kg

$S = (3 \times 10 \times 126)/2 \times 49.5 \times 12.5^2$

$= 0.24 N/mm^2$

SLAB NO. 014_2

b = 50.0 mm

t = 12.2 mm

P = 1.10 Kg

$S = (3 \times 10 \times 126)/2 \times 49.5 \times 12.5^2$

$= 0.24 N/mm^2$

SLAB NO. 014_3

b = 50 mm

t = 12.5 mm

P = 1.055 Kg

$S = (3 \times 10.55 \times 126)/2 \times 50 \times 12.5^2$

$= 0.26 N/mm^2$

SLAB NO. 014_4

b = 49.5 mm

t = 12.5 mm

P = 1.048 Kg

$S = (3 \times 10.48 \times 126)/2 \times 49.5 \times 12.5^2$

$= 0.25 N/mm^2$

Average = (0.24 + 0.28 + 0.26 + 0.25)/4 = 0.30N/mm^2

N.B. Similar calculations were carried out on the rest slabs.

APPENDIX V

SPECIMEN CALCULATIONS FOR THE ADOPTION OF THE TOTAL LOADS/FORCE THAT WILL BE ACTING ON THE STRAW SLAB IN ORDER TO COMPRESS IT USING THE PRESS

THEORY OF SCREW THREADS.

Power screws are in various Thread shapes. The most popular are trapezoidal, buttress and square. Also, threads can be single, double or triple. The screw thread finds application in such mechanical devices as the screw jack, the screw press, the pressing screws of rolling mills e.t.c. In such applications, the screw thread is characterized by comparatively high friction and low efficiency (M. L. AUDU, 1996). A typical application of the thread in a screw jack is shown below.

The screw press consists basically of seven components - the frame, screw, nut attached to a plate, collar, pressing pad and the Base plate. The frame was constructed of (50 mm x 50). Equal angle mild steel. Others were constructed from mild steel. Using a simple design, it was easy to fabricate the equipment in a moderately equipped workshop.

The overall cost of constructing the apparatus amounted to ₦7,280.00 and it has a total mass of 48.2 Kg.

When a load is raised by means of a screw thread, the thread acts as a helix wound around a cylinder (F. Dyson, 1951) and (Khurmi and Gupta, 1990). When the helix is unwrapped from the cylinder, it forms an inclined plane as shown below.

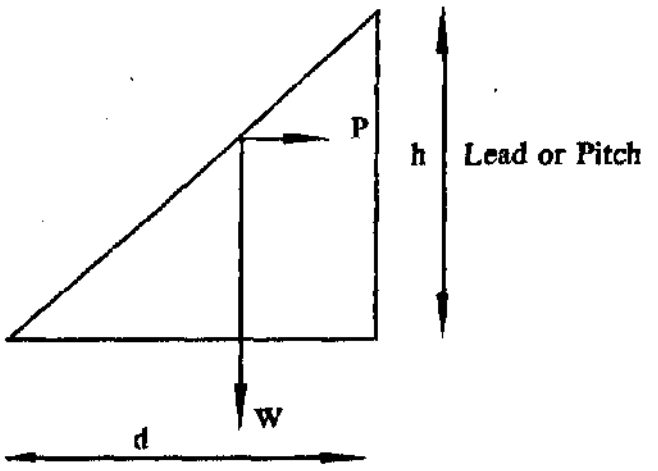


Fig. 4·1 Development of a screw

The horizontal span of the inclined plane is equal to the circumference of the screw (which depends on its mean diameter); and height equal to the lead or pitch.

The simple machine (press) adopted has a central screw with a nut and a metal collar which carries a weight W. The bottom surface of the screw thread is in contact with the upper surface of the thread in the nut, and the development of the surface is an inclined plane as aforementioned.

Neglecting the weight of the screw itself in comparison with W, the problem reduces to that of finding the horizontal effort P required to move a load W up an inclined plane whose inclination with the horizontal is O. (See diagram below).

Let d = Mean diameter of screw.

h = Pitch of screw

= Coefficient of friction.

$$\therefore \tan \theta = \frac{h}{\pi d}$$

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let P = force applied at mean radius.

For motion up the plane, the triangle of forces is as shown above

(fig. 3.8). R1 is inclined at an angle (θ + φ) to W.

from the principle of friction acting between two bodies in contact:

$$P = W \tan (\theta + \phi).$$

= = =

Neglecting friction, the value of P found is the least possible and the friction angle φ = 0.

Let PO = Value of P when friction is neglected, then PO =

$$W \tan (\theta + \phi) - W \tan \theta$$

$$PO = W \tan \theta.$$

When raising a load by means of a screw, the effort is usually applied at the end of a lever which will be less than that required at mean radius.

Let Q = force required at end of a lever.

l = length of lever from centre of screw.

$$Q \times l = \qquad Q = Pd/2$$

$$Q = Pd/2l$$

The Torque required to turn the screw = Ql =

Summarizing the results:

The least force that will be required to lift or lower W is given by

$$PO = W \tan \theta;$$

The effort required to produce this force = Q = Pd/2l

The Torque required to turn the screw = Ql = Pd/2

N.B. W = weight of pressing pad.

d = diameter of screw.

PO = least force required to raise W.

l = length of lever [Tommy bar].

The total load F required to compress the slab is W + POx

where x = No. of pitch of screw.

SAMPLE CALCULATION FOR THE FORMING PRESSURE

Mass of pressing pad = 15.0 Kg ≈ 150 N. (Assume g = 10 m/s2)

Dimensions (size) of pressing pad = 300 mm x 450 mm.

length of lever [Tommy bar] = 300 mm.

Diameter of screw = 18 mm.

Pitch of screw h = 2.5 mm.

PO = Least force required to lift or lower W/Pitch

= W tan θ.

tan θ -

PO = 150 x 0.0442 = 6.63 N. (Min. force to raise W/Pitch).

Effort required to produce this force = Q =

Q =

Torque required to turn the screw = Ql =

= 0.200 x 300 = 60.0 N or

Total load F required to compress the slab per pitch of the screw is

W + PO x = 150 + 6.63 = 156.63 N.

where x = pitch (2.5 mm).

Pressure =

Area of slab = 300 v 450 = 135000 mm2

Pressure = Pressure exerted on the slab/Pitch = 0.0012 N/mm 2.

Hence when the screw is rotated or advanced for just 3 pitch (7.5 mm), the pressure exerted on the slab will be 0.0012 x 7.5 = 0.009 N/mm2. This value is slightly higher than that (0.005 N/mm2) recommended by (Las Anders, 1993).

N.B. The pressure is assumed to be exerted on the straw slab when resistance is felt.