THE EFFICIENCY OF GLUED JOINTS IN MAHOGANY

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DECLARATION

I hereby declare that this thesis is my own research work and has been composed by myself and it has not been previously presented for a higher degree.

All sources of information which are not my own original work are specifically acknowledged by references.



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May, 1994

CERTIFICATION

This project thesis entitled " **THE EFFICIENCY OF GLUED JOINTS IN MAHOGANY**" by Cephas Chihin Suswam, meets the regulations governing the award of the degree of Master of Science (Structural Engineering) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

To the spoken WORD of GOD,

its confession and manifestation in my life.

To my Darlings:

Dr (Mrs) E.A. Suswam (Wife)

and

Saanyol Suswam (Daughter).

Courtesy of whom I changed my diet from milk to meat.

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ABSTRACT

The study investigated the efficiency of glued joints in mahogany - dry zone (Khaya - Senegalensis) using locally (Nigerian) manufactured cascamite powdered resin adhesive.

For the purpose of experimental investigation, five (5) different types of joints namely:

i. Finger glued joint with variation in finger length, pitch and tip width (3 types).
ii. Scarf glued joint with variation in slope (3 types).
iii. Vertical component glued joint with variation in slope (2 types).
iv. Partial Integral joint,
v. Single shear glued lap joint, were investigated. The seasoned mahogany elements were fabricated, assembled in glue (glued) and tested at room temperature for bending (flexure), tension and compression, which are the common load carrying modes of structural timber. All tests were carried out in accordance with B.S. 373: 1957; B.S. 5268: Part 2: 1984; B.S. 5291: 1984; American, ASTM Standard: Part 6: 1958; BS 1204: part 2: 1965; American Forest Products Laboratory Technical Bulletin No. 1512: 1975; NCP2: 1973 et al, however with modification to suit our testing equipments and environments.

Results clearly indicate that, for glued structural mahogany in bending and tension, glued mahogany finger joints with 55mm

finger length, 12.5mm pitch and 1.5mm tip width are most efficient showing a 95% efficiency. For members in compression parallel to grain, the plain scarf mahogany glued joint with slope 1:8 is most efficient showing 98% efficiency. The Efficiencies of glued mahogany joints results obtained from this study for finger glued joints and plain scarf glued joints show that mahogany like in the classification of selected wood species according to ease of bo nding in U.S.A.[22] (River 1987), bonds well with cascamite powdered synthetic resin glue. Ref. Table 2-1. The properties, preparation and application (physical features) of cascamite powdered resin used in the study indicate that it belongs to the rigid thermosetting (Inorganic) group of adhesives. The glue can be speculated to be either Urea-Resin or melamine Resin (formaldehydes). The results of this study also indicate that African mahogany (Khaya-Senegalensis specifically) can conveniently be glued using resin adhesive (moisture-resistant and moderately weather-resistant, MR) contrary to the publication by Timber Research and Development Association, London, Mettem, 1986. The above publication names INT casein as the only glue type suitable for gluing African mahogany.

The determination of nonlinear relationship on the basis of observed data from the seventy-five (75 Nos) test pieces to predict stress and strain values involved non linear regression analysis. Formulae were therefore derived to predict specimens' stress and strain values for each loading mode for the five (5) types of timber glued joints corresponding to their data points

plots and curves of best fit. The formula for the most efficient bending and tension glued structural mahogany joint is

$$\sigma = 0.487 + 0.010\epsilon - 8.409 \times 10^{-7} \epsilon^2$$

exhibiting a standard normal distribution shape.
And the formula for the most efficient glued mahogany joint in compression parallel to grain is

$$\sigma = -0.997 + 0.020\epsilon - 1.346 \times 10^{-6} \epsilon^2$$

exhibiting a curve, assuming a standard normal distribution shape.

σ (stress) and ϵ (strain) are dependent and independent (deterministic) variates - For pairwise data.

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SYMBOLS AND ABBREVIATIONS

a	distance in millimetres between point of application of load and support (L/6)
A	cross-sectional area in millimetre square.
ASTM	American Society of Testing and Materials
B,b	breadth
B.S.	British Standard
B.R	Boil Resistant
C	Compression
C.S. at L.P	Compressive stress at limit of proportionality.
CV	Coefficient of variation
^0C	degrees centigrade
d	depth
E	
E_B, E_c, E_t	modulus of Elasticity in Newton per square millimeter
EVA	Ethylene Vinylacetate
E(y/x)	Regression analysis expected (mean) Value
fbapar	applied bending stress parallel to grain
fbgpar	Dry basic grade stress for bending parallel to grain
fbbppar	permissible bending stress parallel to grain
fcbpar	Basic compressive stress parallel to grain
fcbper	Basic compressive stress perpendicular to grain
fcgpar	Basic compressive grade stress parallel to grain
fcppar	permissible compressive stress parallel to grain
fcapar	applied compressive stress parallel to grain
fig.	figure

f_j	modulus of Rupture in Newton per square millimetre
Fmax	Recorded maximum load in Newton
F.S. at L.M.	Fibre stress at Limit of Proportionality
F.S. at M.L.	Fibre stress at maximum load in Newton per square millimetres
ftapar	applied tensile stress parallel to grain
ftgpar	basic tensile grade stress parallel to grain
ftppar	Permissible tensile stress par to grain
F_1	Load duration
F_4	shape factor
F_5	depth factor
F_6	modification factor for slenderness ratio
g(x)	Predetermined nonlinear function of x.
$g_j(x), j=1,2..m$	Predetermined functions of the independent variable x.
H,h	height (and depth) in millimetre
INT	Interior
KN	Kilo Newton
L,l	length of specimen, the length of overlap, the test span in millimeter
L.P.	Limit of Proportionality
M.C.	Moisture Content
Mmax.	Maximum Moment
M.O.E.	Modulus of Elasticity
MOR	Modulus of Rupture in Newton per square millimetre
MR	Moisture Resistant and moderately weather Resistant

M.F.	Melamine Formaldehyde
n	Number of strength (items) in the sample
NCP	Nigerian code of practice
P	Maximum crushing load in Newton
P^{l}	Load at Limit of Proportionality
P.F.	Phenol formaldehyde
PVA	Polyvinyl acetate
R.F.	Resorcinol formaldehyde
r_x	radius of gyration about x-axis
r_y	radius of gyration about y-axis
R.H.	Relative humidity
S,SD	Sample Standard Deviation
S_l	Specific gravity at test
T	Tension
t	thickness of member/tip width of finger fabs.
T.S. at L.P.	Tensile stress at Limit of Proportionality
TS at M.L.	Tensile stress at Maximum Load
U	apparent mean shear at failure
U^{l}	permissible working stress in mean shear
U.F.	Urea - formaldehyde
U.K.	United Kingdom
UDL	Uniformly distributed load (Rectangular)
UL	Ultimate Load
U.S.A.	United States of America
V	Basic working stress in shear parallel to grain
V^{l}	a constant

V_1	Volume of sample at test
W_0	Weight of specimen, oven dry in kilogramme
W_1	Weight of specimen at test
WBP	Weather Boil and Proof
$X_,$	Every successive strength value
X_i	Regression analysis independent variate
X	Percentage moisture content
$\bar{X}$	Arithmetic mean
Y	Regression analysis dependent variate
Z	Section modulus
ϵ_c, ϵ_t	Strain in Compression and Tension
Σ	Summation
α, ß	Regression analysis constants
$\epsilon_{L.P.}$	Strain value at Limit of Proportionality
$\sigma_{L.P.}$	Stress at Limit of Proportionality
%	Percentage
>	greater than
0	angle
τ_{par}	Shear stress parallel to grain
τ_{gpar}	basic shear grade stress parallel to grain
λ_x	Slenderness ratio about x-axis.

CHAPTER ONE

1.0 INTRODUCTION

1.1 DEFINITION AND BACKGROUND

Timber as a material can be defined as a low density, cellular, polymeric composite as such does not conveniently fall into any one class of materials, rather tending to overlap a number of classes. Timber is said to have high strength performance and low cost and is described as the World's most successful fibre composite, (Illston et al, 1979).

Timber has been used as a structural material from the earliest times: examples can be traced to the neolithic era, dating back to about 800 B.C., but it was not until 1678, when Robert Hooke established the fundamental relation between stress and strain, that adequate theory was available to guide designers.

Just like steel, timber elements must be joined together and for timber more probably due to limitation of growth. Timber elements are usually joined together by means of nails, bolts, rivets, screws, Connectors and glues. Glued joints in timber are more efficient in the distribution of load. Concentrated local stresses are not so pronounced as for nails, screws, bolts etc. Large spans can be bridged with built-up arches and girders much more satisfactorily than with solid timber, and at considerable savings in cost, compared with steel or Reinforced Concrete. Reece P.O., in his words said: "Gluing does for timber what welding does for steel; it enables joints to be made without

cutting any material out of the members joined and makes it possible for the designer to take advantage of all the economies associated with monolithic construction" (Desch, 1956).

Strong, rigid thermosetting adhesive (Phenol,Resorcinol, melamine, Urea and their combinations) are generally not used for structural assembly joints since there is little information available on the design of such joints. Efforts are underway in the United States of America (U.S.A.) and in Europe to develop design method and standards for structural glued assembly joint, but as yet there are no standards (River, 1992).

Glued joints in timber have higher efficiencies than other timber joint connectors. Timber joints made with thermosetting adhesive are durable. Structurally assembled glued timber joints made with strong, rigid thermosetting adhesive is a new field/area of research, currently been investigated in both Europe and America to produce design methods and standards for the structural glued assembly joints. Very little has been done on the gluability of West African hardwoods. With these revelations, this study titled 'Efficiency of glued joints in timber', particularly in hardwoods of Nigeria was formed. The study seeks to use a common Nigerian adhesive and selected timber species to study efficiencies of five (5) different types of bonded joints, with emphasis on compressive, Bending and tensile strengths.

1.2 GLUED JOINTS

Glued joints are governed by the dimensions and physical properties of the wood used, and the shape of the joint, rather than by qualities of the particular glue selected, even though gluing technique is an important factor. Glues of phenol formaldehydes or derivatives or homologues of phenol reacted with suitable aldehydes are damp proof, proof against the ravages of micro-organisms and against the lapse of time: They are as stable and durable as the timbers they join (Desch, 1956).

The commonest types of glue joints are End-Grain Bonds. End-grain bonds are scarf joints, butt joints and finger joints, shown in Fig. 1.0.

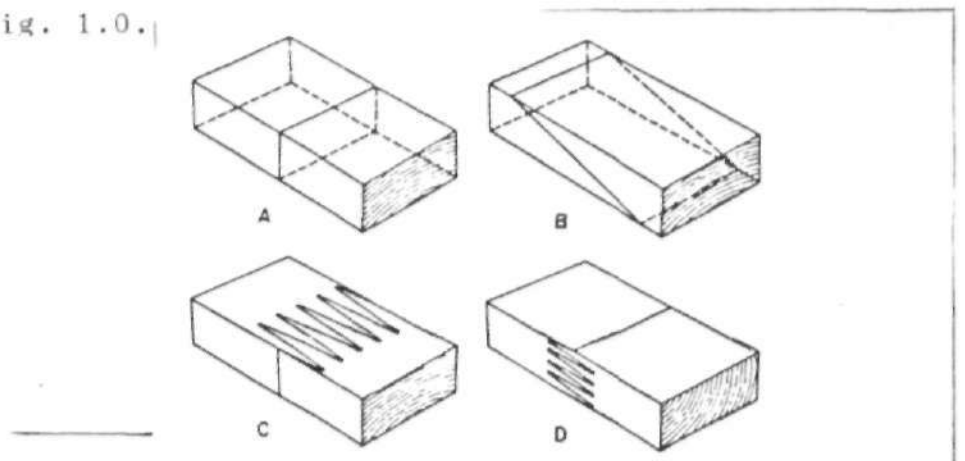


Figure 1-0 Types of end-to-end grain joints for lumber. *A*, Butt joint. *B*, Scarf joint. *C*, Vertical finger joint, the most common type for structural purposes. *D*, Horizontal finger joint. (Photograph courtesy of U.S. Forest Products Laboratory.)

Figure 1.0. Types of end-to-end grain joints for lumber. A, Butt joint. B, Scarf joint. C, Vertical Finger joint, the most common type for Structural purposes. D, Horizontal finger joint. (Courtesy of U.S. Forest Laboratory).

To obtain acceptable strength in pieces spliced together end wise, it is necessary to make a scarf, finger or other sloped joint. Plain scarf with a low slope generally develops the highest strength, but is also the most wasteful of materials and

requires considerable care both in machining and gluing to obtain consistently high - quality joints.

Scarf joints have relatively large, nearly lateral surfaces and are therefore much stronger than butt joint. The tensile strength of finger joints falls between that of butt joints and scarf joints, depending on the angle of the fingers and on the size of butt and areas at the finger tips. In bending, finger joints fare better.

Glued joints can last for ever if nothing damages them, they may be weakened and destroyed not only by fire, living organisms and mechanical force, but also by moisture as such and by changing moisture contents. In fact moisture is by far the most important factor in glue bond durability (Selbo, 1975).

1.3 EFFICIENCY AND DURABILITY OF GLUE JOINTS

End joint efficiency is percentage ratio of the strength of the end joint to the strength of unjointed timber of the same (or similar) cross-section and species containing no strength reducing characteristics.

Forest products laboratory - Forest service U.S. Department of Agriculture through tests on specimens containing scarf joints stressed in tension indicated the average strength ratios given below:

Table 1.0 Scarf Joint Efficiencies

Slope of Scarf (in Soft Wood)	Strength Ratio (jointed/Non jointed)
	Pct.
1:12 and less steep	90
1:10	85
1:8	80
1:5	65

Table 1.1 Finger Joints Efficiencies

Efficiency Rating of Some Finger Profiles (in Soft Wood)

FINGER PROFILES				
Length	Pitch	Tip Width	Efficiency rating in bending and tension parallel to grain	Efficiency rating in compression parallel to grain
mm	mm	mm	%	%
55	12.5	1.5	75	88
50	12.4	2.0	75	83
40	9.0	1.0	65	89
32	6.2	0.5	75	92
30	6.5	1.5	55	77
30	11.0	2.7	50	75
20	6.2	1.0	65	84
15	3.8	0.5	75	87
12.5	4.0	0.7	65	82
12.5	3.0	0.5	65	83
10	3.7	0.6	65	84
10	3.8	0.6	65	84
7.5	2.5	0.2	65	92

Tables 3 and 104 of BS 529: 1984 sections four (4) and B.S. 5268: Part 2: 1984 Appendix F, lists efficiency ratings of finger joints with profiles visible either on the face or edge of rectangular section (at least four complete fingers must be present) in softwood.

Joints and products that were made with phenol formaldehyde, resorcinol formaldehyde, or phenol-resorcinol formaldehyde adhesives have proved more durable than the wood when exposed to warmth and dampness, to water, to alternate wetting and drying, and to temperatures sufficiently high to char the wood. These glues are entirely adequate for use in products that are exposed indefinitely to the weather as illustrated in Figure 1.2.

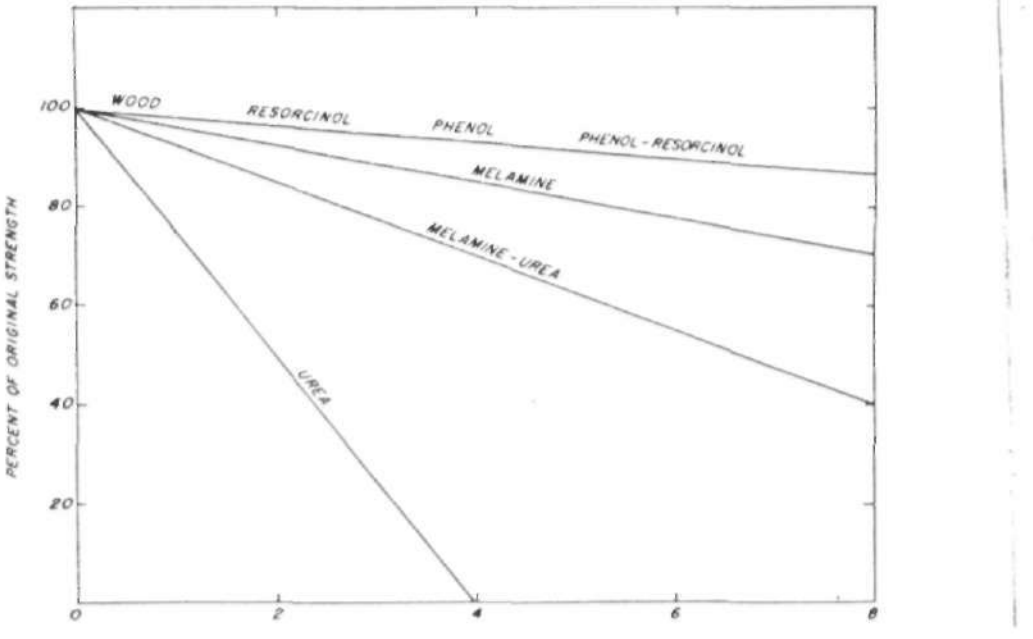


Figure 1.2 Schematic illustration of the relative rates of degradation of small specimen bonded with several rigid thermosetting.

1.4 ADHESIVES FOR WOOD

An adhesive is defined as a material which when applied to surfaces can join them together in such away that separation is resisted. In timber jointing, adhesives are used with effects similar to welding of steel members. Wood adhesives are usually applied thinly to the surfaces to be jointed and after some time pressed together to become one. To enable the gluing effect, clamps or nail or bolts are used to keep members together until the glue line has sufficiently cured.

Adhesives are of two (2) categories, namely the organic and the inorganic adhesive. The organic adhesives derived from plants and animals were until the middle of the 20th century the principal adhesives in use. Examples of such adhesives are animal glues; gelatin; casein; Blood albumen Haemoglobin and biological adhesives. Inorganic adhesives first appeared on the market in the early 1930s. Inorganic adhesives are either thermoplastic or thermosetting adhesives. For wood jointing thermosetting adhesives are more frequently used and the commonest types are the phenolic and Aminoplastic groups which comprise phenol and Resorcinol formaldehyde; Urea formaldehyde and melamine formaldehyde; Polyvinyl acetate and copolymer emulsions, elastomer-based solutions and latex, epoxy isocyanate and acrylic (Selbo, 1975).

Common glues used locally for wood joining for structural and non structural work are cascamite powdered resin, emulsions of ponal, pronel, Dunlop, climax, Durop. Amaga and Armens.

B.S. 1204 classifies the adhesive into the following classes:

i. Type WBP (Weather and boil-proof). Highly resistant to weather, micro organism, cold and boiling water, steam and dry heat.

ii. Type BR (Boil resistant). Good resistance to boiling water, but fail under prolonged exposure to weather. Withstand cold water for many years. Have good resistance to micro-organisms.

iii. Type MR (Moisture resistant) moderately weather resistant and will survive full exposure for a few years. Withstand prolonged exposure to cold water, but only limited exposure to hot water. Resistance to micro-organisms.

iv. Type INT (Interior). Withstand cold water for a limited time only and only suitable for occasional damp conditions. Not necessarily resistant to micro-organisms (Everett, 1981).

The adhesives are the following types:

1.4.1 Adhesives Derived from Natural Products

1.4.1.1 Animal Glues

Animal glues are made from hides, skins, bones and sinews and they set slowly, they are also sensitive to moisture. They are supplied in solid form or as a jelly for hot application, and as a prepared liquid for cold application. Except for minor

interior uses, animal glues are rarely used for timber jointing. Animal glues have brown to white colouration.

1.4.1.2 Casein Glues

Casein glue, described by BS 1444: 1970 as cold setting adhesive. It is powder adhesive for wood and is made from soured mild curds (sour milk) dried and ground to a fine powder and mixed with an alkali and fillers.

Caseins is easy to use at ordinary temperatures. In dry conditions the hardened glue has good Resistance to heat and develops high strength. However, when wet it loses strength and is not durable externally. Casein is suitable for bonding wood to linoleum, plaster-board, asbestos - cement and to decorative laminated plastics sheets and for general joinery: White to tan.

1.4.1.3 Bituminous Adhesives

B.S.3940: 1965 describes Bituminous adhesives as adhesives based on Bitumen or coal tar. They are not usually use for wood joining. Their commonest use in wood work is for laying wood flooring blocks and mosaic. Bituminous adhesives has a tendency to flow at higher temperatures which can smear wood.

1.4.2 Adhesives Based on Synthetic Thermoplastics

Thermoplastics group of adhesives are not normally use for wood jointing.

1.4.2.1 Polyvinyl Acetate (PVA)

B.S. 4071: 1966 describe Polyvinl acetate (PVA) emulsion adhesives for wood are white liquids, transparent when set, which generally do not discolour other material. PVA is suitable for joints which will not be required to resist high continuous stresses, in particular for bonding joinery, paper, leather, cloth and similar materials to be used in dry conditions.

1.4.2.2 Hot-melt Adhesives

These adhesives are 'solid' thermoplastics - such as sealing wax-but modern types are usually based on ethylene-vinylacetate (EVA) copolymers. Hot-melt adhesives are very suitable for flow line production - these are no flammable solvents and the bond is formed in seconds. Adhesion is good to wood, metals and plastics.

1.4.3 Synthetic Resin Thermosetting Adhesives

These adhesives are capable of extremely high strength, in some cases even when joining metals and although they are combustible their performance at high temperature is superior to the natural and thermoplastics types. This is the most durable adhesive group usually used for structural assemblage, (structural bonds) and are classified as structural adhesives. The adhesives in this group are:-

1.4.3.1 Phenol Formaldehyde (PF)

Phenol Formaldehyde adhesives are classed as WBP (not affected by weather or boiling). They are provided in an alkaline solution or film suitable only for weather-proof or marine plywood manufacture, which will set at temperatures from 115°C.

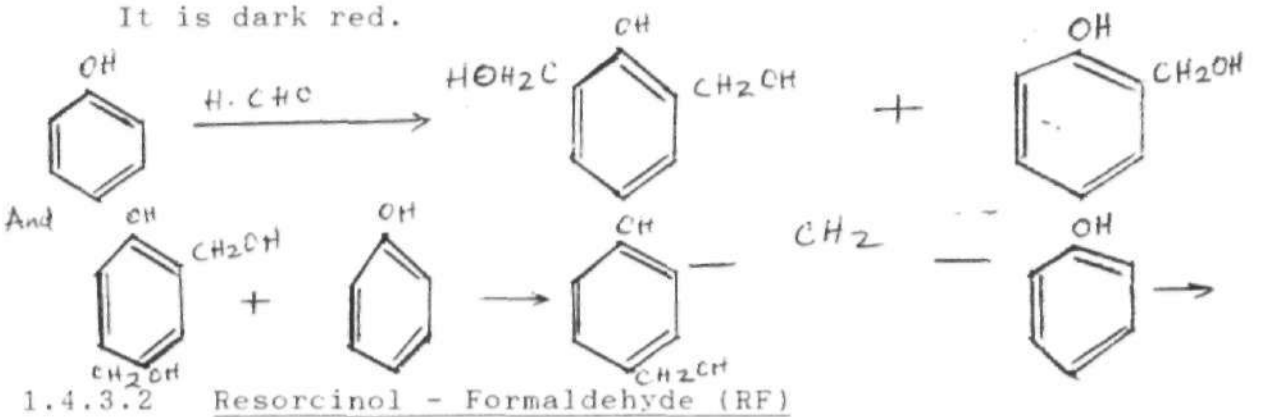
Phenol condenses with formaldehyde in the presence of either acid or alkali initially to form a methylol phenol and then a dimethylol phenol.

The second stage of the reaction involves the reaction of the methylol groups with further phenol and hence, with unsubstituted phenols to the formation of much branched tree structures.

Phenol - formaldehyde is a product of a chemical reaction:-

Phenol + Formaldehyde = Phenol - Formaldehyde.

It is dark red.



1.4.3.2 Resorcinol - Formaldehyde (RF)

This reddish - purple adhesive is more costly than phenol formaldehyde but easier to use at low curing temperatures, and more rapidly up to about 70°C. It has a long shelf life and the pot life after adding a hardener, usually in powder form, is from

1 to 5 hours at 20°C.

Although water-soluble until cured, when hardened the durability classification is WBP.

Resorcinol formaldehyde is used to form extremely strong and durable joints in timber structures with a moisture content not exceeding 15 percent at the time of bonding. It is also suitable for bonding plastics, rubber and alkaline materials such as asbestos - cement sheets.

The chemical formulation is:

Resorcinol + Formaldehyde ----> Resorcinol - Formaldehyde.

1.4.3.3 Urea Formaldehyde (UF)

Many brands are sold as dry powders. Others as liquid; may be blended with melamine or other resins.

Dry form mixed with water; hardeners, fillers, and extenders may be added by user to either dry or liquid form; applied at room temperatures, some formulas cure at room temperatures, others require hot - pressing at about (121°C) 250°F.

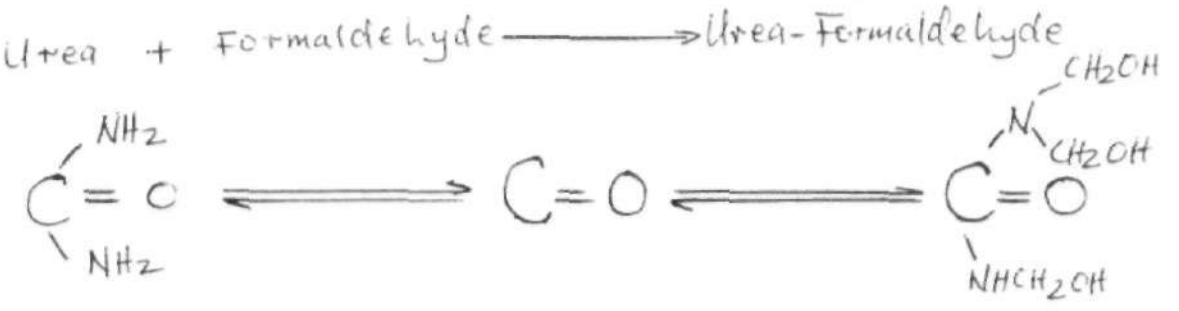
High in both wet and dry strength; moderately durable under damp conditions; moderately at low resistance to temperatures in excess of 49°C (120°F); white or tan.

Widely used in building where they are not exposed to the weather. Uses include: Hard - wood plywood for interior use and furniture; interior particle board; under layment, flush doors, furniture core stock.

Normal UF glues are classified as MR but inclusion of

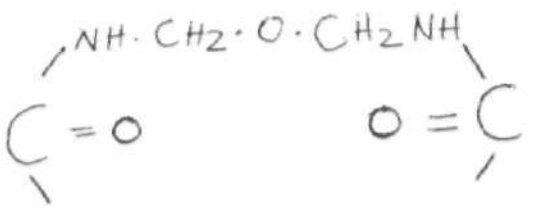
resorcinol or melamine in the hardener (fortified UF glues) brings the durability classification up to BR.

Urea reacts with formaldehyde by condensation in the presence of acid or base to give Urea - formaldehyde:

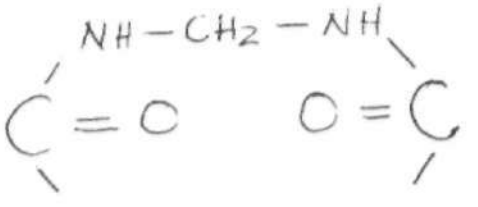


By a series of reactions of this type carried out in aqueous solution a highly branched tree can be formed and the solution gradually thickens to a syrup.

There are further complexities of reaction, for in alkaline conditions two monomethylol groups can condense to link two growing trees together thus:



In acid condition the cross-link is more likely to be



1.4.3.4 Melamine Formaldehyde (MF)

Comparatively few brands available; usually marketed as a powder with or without catalyst.

Melamine resin is provided as a film for setting at 100°C or as a powder to be mixed with water and applied at room temperatures; heat required to cure 121°C to 149°C (250 to 300°F). High in both wet and dry strength; very resistant to moisture and damp conditions depending on the type and amount of catalyst; the colour is white or tan.

The durability classification of melamine-formaldehyde adhesive is B.R.

Primarily a fortifier for Urea resin for hardwood plywood, end-jointing and edge-gluing of lumber, and scarf joining softwood plywood. High - frequency cure compatible.

Melamine + Formaldehyde ---> Melamine - Formaldehyde.

1.4.3.5 Epoxy - Resin

These two part resin adhesives, e.g., Araldite (CIBA [A.R.L.] Ltd.,) are costly but posses remarkable properties with high adhesion to almost all surfaces, in most cases both internally and externally.

Epoxy resin refers in a broad sense to a wide variety of polymers characterized in their simplest form by an oxygen atom linked to each of two adjacent carbon atoms on a chain, as in ethylene oxide.

Epoxide adhesive can be resilient, electrical resistance is

high and they are water and water vapour proof. They are highly resistant to water, most acids, alkalis and solvents.

Most commonly use in combination with other resins for bonding metals, plastics, and materials other than wood; bonding wood-to-wood, specially items like; repair of laminated beams: fabrication of cold molded wood boats and wind generator blades. Concrete/concrete bonds, e.g. for bonding precast segments of shell roof of sydney opera house.

1.4.3.6 Phenol - Resorcinol

Phenol-Resorcinol resins are modifications of straight resorcinol resin adhesives produced by polymerizing the two resins (Phenol-formaldehyde and resorcinol formaldehyde).
PHENOL + RESORCINOL + FORMALDEHYDE ---> PHENOL - RESORCINOL - FORMALDEHYDE.

The principal advantage of the copolymer resins over straight resorcinol resin is their significantly lower cost, because the price of phenol is much more lower than that of resorcinol. This cost advantage apparently is achieved without any significant losses in joint performance. For wood gluing, the volume of phenol resorcinol Proportions of two resin components in the copolymer are not generally revealed by the manufacturers like their components, the copolymer resins are dark reddish liquids and are prepared for use by adding powdered hardeners. The hardeners generally consist of paraformaldehyde and walnut shell flour, mixed in equal parts by weight.

1.4.3.7 Melamine-Urea Resins

Melamine-Urea resins are a special group of hot-press adhesives produced by either dry blending urea and melamine resins or by blending the two separate resins in liquid solution and then spray drying the mixture. In either case, the resins are supplied by the manufacturers as powders, to be prepared by adding water and catalyst.

The melamine urea combinations are used in much the same way as hot-press ureas and melamine glues, curing at 116°C (240°F) to 127°C (260°F) in manufacture of plywood. The melamine-urea resin glues offer advantages for hardwood in that they are colourless, more durable than urea resins, cheaper than straight melamine or resorcinol resins, and capable of curing at lower hot-press temperatures than conventional phenol resin glues.

Urea + Melamine + Formaldehyde ---> Urea - Melamine - Formaldehyde.

1.5 AIM AND OBJECTIVES

The aim of the study is to determine the Efficiency of different glued joints in Mahogany. The study is done on mahogany (dry-zone; Khaya Senegalensis) because of the area of study/research is in the Savannah Region of Nigeria where mahogany (dry-zone) is cheaply available.

The main objectives of this study (research) are:-

i. To provide necessary data on the Efficiency (and strength) of glued joints in mahogany (dry-zone) after

subjecting the specimens to Bending, compressive and Tensile stresses.

ii. To assess the suitability and gluability of mahogany (dry-zone hardwood) with the Nigerian formulated cascamite synthetic resin powdered glue for structural utility in the solid form.

iii. To provide necessary data that can facilitate estimation of failures in live mahogany sizes; after watching specimens loaded beyond their designed loads to failure.

iv. To recommend the most suitable types of glued joints corresponding with positions in a structure like:- Beams, columns, struts and tie.

v. To attempt to provide data as part of Nigerian glued joints designs and standards in the near future.

1.6 SCOPE AND LIMITATIONS

The mechanical properties of glued joints in mahogany investigated are:-

Bending strength; compressive and Tensile strength; other physical observations were moisture content determination, density and elastic modulus were also computed and compared with clear specimens for EFFICIENCY RATINGS.

The timber type selected for the tests was mahogany for its proximity to Zaria. It is cheaply found around Zaria environs:- Saminaka, Zonkwa, Kafanchan, Kagoro, Kachia, Kotongora, Abuja and

Zaria area itself.

The tests were done in accordance with specifications of B.S. 373: 1957 (methods of testing small clear specimens of timber); ASTM standard: Part 6 1958 (American Society for Testing Materials); B.S. 1204: Part 1: 1964 (specification for resin adhesives); B.S. 1204: Part 2: 1965 (specification for synthetic resin adhesives); NCP2: 1973 - structural use of timber; B.S. 5268: Part 2: 1984; B.S. 5291: 1984 (code of practice for permissible stress design, materials and workmanship and manufacture of finger joints of structural softwood respectively); Bulletins: 1512: 1975 - Forest Products Laboratory - Forest Service U.S. Department of Agriculture and 1986 Publication of TRADA - Structural Timber Design and Technology; however all specifications were modified to suit conditions of our environment: available laboratory equipments, live sizes of Nigerian timber and quality of workmanship and manufacture of glued joints in mahogany were factors of our modification.

All specimens were fabricated and assembled with Nigerian mahogany and cascamite synthetic resin powdered glue and tested parallel to grain.

1.7 TESTS

1.7.1 Bending Strength Test

If forces act on a piece of material in such a way that they tend to induce compressive stresses over one part of a cross

section of the piece and tensile stresses over the remaining part, the piece is said to be in bending. The common illustration of bending action is a beam acted upon by transverse loads.

In tests to determine the behaviour of materials in bending, attention is usually confined to beams. It is assumed that the loads are applied so that they act in a plane of symmetry, so that no twisting occurs, and so that deflections are parallel to the plane of the loads. It is also assumed that no longitudinal forces are induced by the loads or by supports. The stresses induced by a bending moment may be termed bending stresses. For equilibrium, the resultant of the tensile forces T must always equal the resultant of the compressive forces C. The resultants of the bending stresses at any section form a couple that is equal in magnitude to the bending moment. When no stresses act other than the bending stresses, a condition of "pure bending" is said to exist.

Bending action is beams is often referred to as "flexure". Flexure is also referred to bending tests of beams subject to transverse loading.

The variations in total transverse shear and in bending moment along a beam are represented by shear and moment diagrams as illustrated in some cases of concentrated loading below, in Fig. 1.3. Symmetrical two-point loading gives a condition of pure bending (constant moment) over the central portion of the span (see Fig. 1.3b).

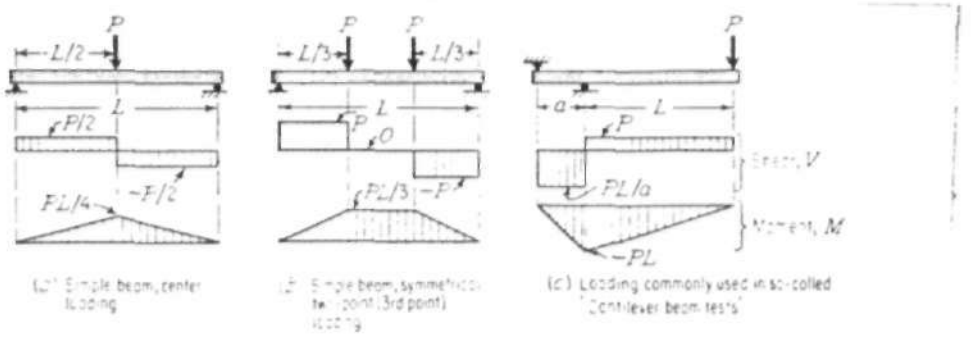


Fig 1.3 Shear and moment diagrams.

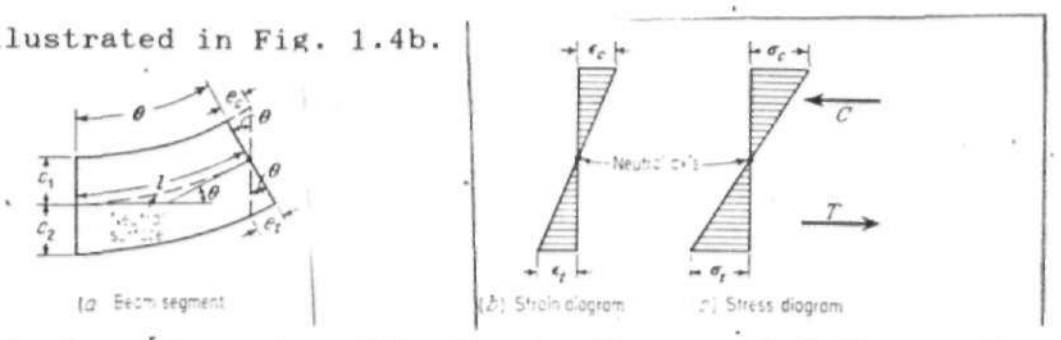
(a) simple beam, centre loading (b) Simple beam, symmetrical two-point (3rd point) loading (c) Loading commonly used in so- called "canti-lever beam tests".

Fig. 1.3 Shear and Moment Diagrams

In a cross section of a beam, the line along which the bending stresses are zero is called the neutral axis. The surface containing the neutral axes of consecutive sections is the neutral surface. On the compressive side of the beam the "fibres" of the beam shorten, and on the tensile side they stretch; thus the beam bends or deflects in a direction normal to the neutral surface, becoming concave on the compressive side (See Fig. 1.4).

In pure bending the strains are proportional to the distance from the neutral axis in the range of in elastic action as well as in the of elastic action. This is referred to as a condition of "plane bending" i.e., plane sections before bending remains

plane sections after bending. The elongation or shortening of the fibres in any given length of beam over which the moment is constant divided by that length gives unit fibre strain, as illustrated in Fig. 1.4b.



(a) Beam Segment (b) Strain diagram (c) Stress diagram

Fig. 1. 4 Fibre Strains and Stress Due to Bending Within the Proportional Limits.

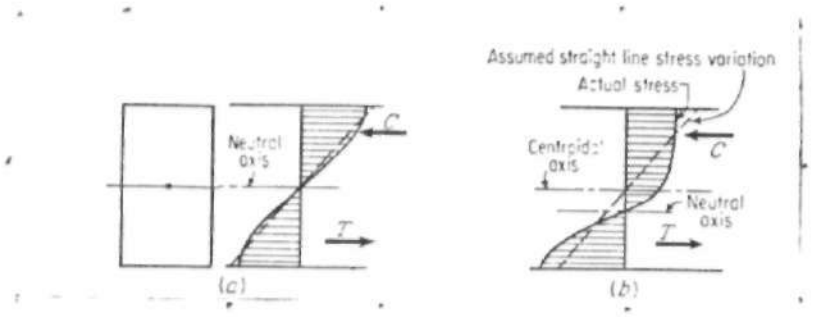


Fig. 1.5 Fibre Stress above the Proportional Limit

If the material does not have the same stress-strain characteristics in tension as in compression, the neutral axis must shift toward the stiffer side of the beam in order to maintain equality of the resultants of the tensile and compressive forces, as shown in Fig. 1.5.

A wooden Beam also may fail in a number of ways as shown below in Fig. 1.6.

Fig. 1.6 Various modes of failure of wood Beams (ASTM 143).

Various modes of failure of wood beams (ASTM D 143).

(1) It may fail in direct compression at the concave compression surface.

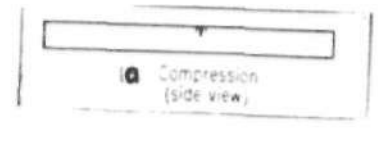


Fig. 1.6(a) Compression (side View)

(2) It may break in tension on the convex tension surface. Since the tensile strength of wood parallel to the grain is usually greater than its compressive strength, the neutral axis shifts toward the tensile face so as to maintain equality of the tensile and compressive forces, as shown in Fig. 1.5b. Therefore, the first visible signs of failure may be in the tensile face even though the wood is stronger in tension than in compression. This type of failure occurs only in well-seasoned timbers, since green pieces usually fail in compression before rupturing the tension fibres.

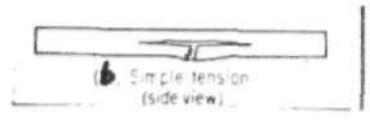


Fig. 1.6(b) simple tension (side view)

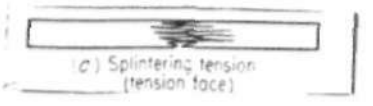


Fig. 1.6(c) Splintering tension (tension face)

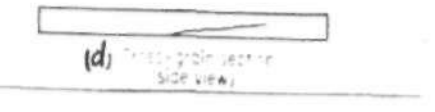


Fig. 1.6(d) Cross-grain section (side view)

(3) It may fail by lateral deflection of the compression fibres acting as a column.

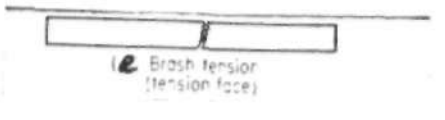


Fig. 1.6(e) Brash tension (tension face) similar to: Crushing (in column); shearing (in column); plane of rupture at acute angle.

(4) It may fail in horizontal shear along the grain near the neutral axis. This type of failure is sudden and more common in well-seasoned timbers of structural sizes than in green timbers or in small beams.

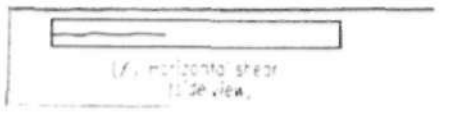


Fig. 1.6(f) Horizontal shear (side view)

(5) It may fail in compression perpendicular to the grain at points of concentrated load.

For beams of brittle material the nominal fibre stress at rupture as computed by the flexible formula (the "modulus of

rupture" in bending) is usually appreciably greater than the true tensile strength of the material. The ratio of the modulus of rupture to true tensile strength is about 1.8 for cast iron and about 1.5 to 2.0 for concrete. The ratio of modulus of rupture to compressive strength is about 0.5 for cast iron, about 0.15 to 0.20 for concrete, and about 2 for wood (considering the compressive strength parallel to grain).

Flexural tests on beams are usually made to determine strength and stiffness in bending; occasionally they are made to obtain a fairly complete picture of stress distribution in a flexural member. Resilience and toughness of materials in bending are also determined from beam tests.

Stiffness of a material may be determined from a bending test in which the loads and deflections are observed. The modulus of elasticity for the material in flexure is computed by use of an appropriate deflection formula. The value of the modulus of elasticity may then be used to compute the elastic deflection of beams of the same material but of other size, shape, or loading, although some error may be involved.

To produce a flexural failure, the specimen must not be too short with respect to the beam depth, and conversely, if a shear failure is desired, the span length must not be long. Values of L = 6d to L = 12d, in which L = length and d = depth, serve as an approximate dividing line between the short, deep beam that fail in shear and the long, shallow beams that fail in the outer fibres.

Standard test beams of small clear pieces of wood are 2 by 2 by 30 in. in size and tested on a 28-in. Span under centre loading (ASTMD 143) or 2cm by 2cm by 30 cm in size and tested on a 28cm span under centre loading and those of the four-point loading test piece 2 in. by 2 in. by 40 in., the distance between the point of the support shall be 36 in and the distance between the points of application of the load and the supports shall be 6 in. (B:S. 373: 1957). Timber in structural sizes are often tested under third-point loading on a span of 15ft (4.5m) ASTMD 198; common sizes of large wood test beams are 16ft (4.8m) long with nominal cross sections of 6 by 12 in., (150mm x 300mm) or 8 by 16 (200mm x 400mm).

1.7.2 Compressive Strength Test

The term compression test is usually taken to refer to test in which prepared specimen is subjected to a gradually increasing (i.e. "static") uniaxial load until failure occurs. In a simple compression test, it is accomplished by subjecting a piece of material to end loading which produces crushing action.

Compression specimens are limited to such a length that bending due to column action is not a factor. The ideal conditions are limited to the trueness to form the test piece by the effectiveness of the holding or bearing devices, and by the action of the testing machine.

When properly conducted tension and compression tests on suitable test specimens, come closer to evaluating fundamental

mechanical properties for use in design and prediction of material performance.

There are several limitations to the compression test to which attention should be directed.

1. The difficulty of applying a truly concentric or axial load.
2. The loading is relatively unstable in contrast to tensile loading. There is always a tendency for bending stresses to be set up and for the effect of accidental irregularities in alignment within the specimen to be accentuated as load proceeds.
3. Friction between the heads of the testing machine or bearing plates and the end surface of the specimen due to lateral expansion of the specimen. This may alter considerably the results that would be obtained if such a condition of test were not present.
4. Larger cross-sectional area specimen will require relatively large-capacity testing machine or specimens so small and therefore short to obtain proper degree of stability and strain measurements of suitable precision.

It is presumed that the simple compression characteristic of materials are desired and not the column action of structural members so that attention is here confined to the short compression block.

Specimen for compression tests of small clear piece of wood

parallel to the grain are 2 by 2 by 8 in., (50 x 50 x 200mm) rectangular prisms. compression tests perpendicular to the grain are made on nominal 2 by 2 by 6 in., (50 x 50 x 150mm). ASTMD 198 specifies compression test of timber in structural sizes.

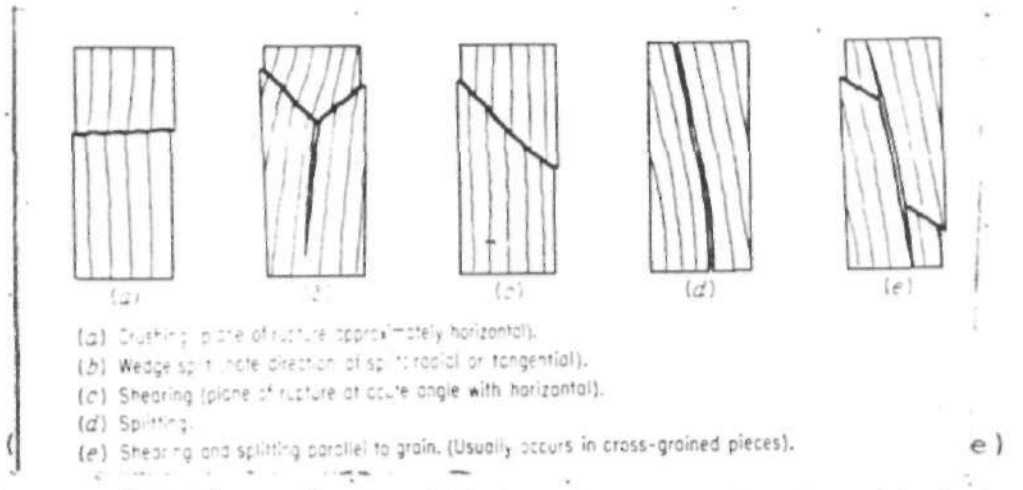


Fig. 1.7 Types of Failure in Wood Under Compression Parallel to the Grain (ASTMD 143)

(a) Crushing (Plane of rupture approximately horizontal).
(b) Wedge split (note direction of split: radial or tangential).
(c) Shearing (plane of rupture at acute angle with horizontal).
(d) Splitting.
(e) Shearing and splitting parallel to grain. (Usually occurs in cross-grained pieces). Table 4.2.1.1 in Chapter 4 gives the explanation of the causes and positions of failure.

Wood exhibits, under compressive loading, a behaviour peculiar to itself. Wood is isotropic material, being composed of cells formed by organic growth which align themselves to form a series of tube or columns in the direction of the grain. For this structure, the elastic limit is relatively low, there is no definite yield point, and considerable set taken place before failure. Loads normal to the grain, the load that causes lateral collapse of the tubes or fibres (crushing) is the significant

load. For loads parallel to the grain, not only is the "elastic" strength important but also the strength at rupture. Rupture often occurs because of collapse of the tubular fibres as column. Various types of failure of wood load parallel with the grain are described by the sketches in Fig. 1.7.

1.7.3 Tension Test

The tensile strength of wood is relatively high, but it can not always be effectively utilized in structural members because of low shear resistance, which causes failure at the end connections, using bolts, split rings or shear plate connectors before the full tensile resistance of a member can be developed.

Prepared specimens for tension tests are made in a variety of forms. The cross section of the specimen is usually round, square or rectangular. The central portion of the length is usually wasted (of smaller cross-section than the end portions) in order to cause failure to occur at a section where the stresses are not affected by the gripping device.

In a simple tension test, the operation is accomplished by gripping opposite ends of the piece of material and pulling it apart.

To obtain uniform stress distribution across critical section, the reduced portion of the piece is often made with parallel sides for its entire length, although many types of specimens are made with a gradual taper from both ends of the reduced section to its mid-length.

A specimen should be symmetrical with respect to a longitudinal axis throughout its length in order to avoid bending during application of load.

CHAPTER TWO

LITERATURE REVIEW

2.1 LITERATURE REVIEW: GENERAL

The structural use of hardwoods is generally limited to bearing plates and similar situations where a high bearing stress is required[21] (Reece, 1949).

The gluability of a number of hardwoods was investigated in a work carried out at TRADA (Timber Research And Development Association) in the 1960s (Chugg and James 1965). Five types of structural adhesives were employed in the trials, these included a casein, type INT (Interior), three synthetic Resins of the type WBP (Weather-Proof and boil-proof), and an Urea-Formal-dehyde, type MR (Moisture-Resistant and Moderately Weather Resistant. This study employed timber of mahogany dry-zone specie and cascamite resin glue type MR).

On the basis of the requirement that no significant difference should be noted between the shear strength of the glue line and that of the timber itself, ten tropical or warm temperature zone hardwoods were shown to be suitable with one or more of the WBP adhesives. Eight of these ten were suitable with one of the WBP adhesives[16] (Mettem, 1986).

A lot of Research have been done on Adhesives, Timber and the gluability of a number of softwood and hardwoods in Europe and America. However, little is seen or heard about such works in Africa.

The Forest Products Laboratory - Forest Service U.S. Department of Agriculture, Maison, 1916., Princes Risborough Laboratory, London, 1930. (The Timber Research and Development Association, London), Wood Research Institute Finland, Swedish Institute for wood technology Research, Stockhelm, Drottning Kristinas and other Forest Product Research Laboratories in Canada, Australia, India and Malaya established during the 1900s war have been disseminating useful technical information on timber and the Laboratories in Madison and Washington DC of USA and the London Prines Risborough provides the bulk of literature review to this study.

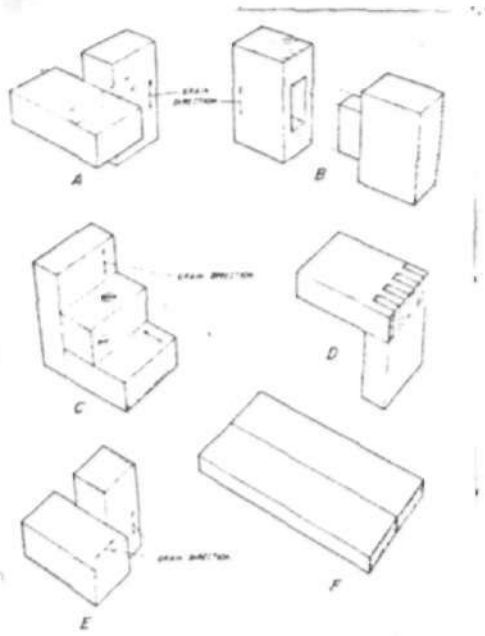
The forest Products Laboratory in their Technical Bulletin No. 1512 (Selbo, 1975)[25] reported the various experimental results on gluability of woods. Three types of glues; casein, urea and Resorcinol were used to form joints with white oak, mahogany and silka spruce with varying densities and shrinking and swelling characteristics for three soak-dry cycles. The performance was that with each adhesive type, the joints in the species of the highest density and greatest shrinkage (white oak) developed the largest amount of failure in glue joints; the joints in the lightest species (sitka spruce) developed the least glue failure. It was suggested that the glue and gluing condition that gave excellent bond on light sitka spruce may not have been adequate for a dense wood such as white

oak[22,25]. (Selbo, 1975 and River 1987).

The Laboratory discovered that to obtain acceptable strength in pieces spliced together endwise lumber, the plain scarp with a low slope (1:12 and lower) can develop almost the full strength of wood, however, it is also the most wasteful of material and require considerable care both in machining and gluing to obtain consistently high-quality joints. Vertical finger joint; cut perpendicular to wide face of board is the most commonly used finger joint for structural purposes[25] (Selbo, 1975)

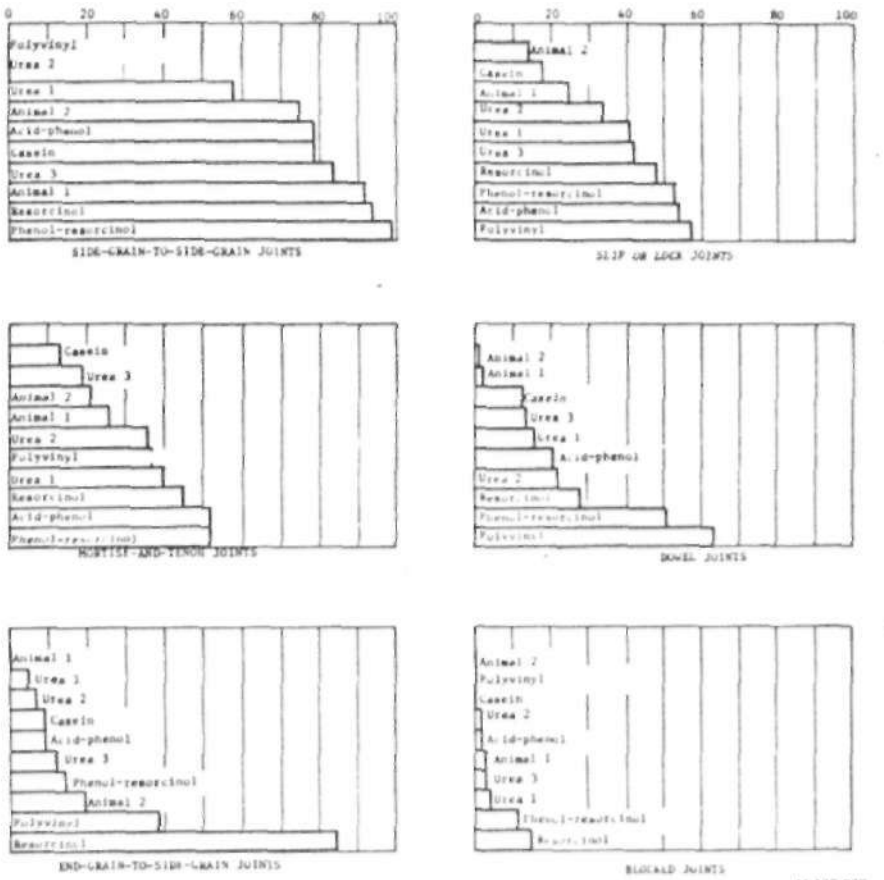
In a study on performance of certain types of furniture joint (Fig. 2.1) bonded with different adhesives: Domel; Mortise and Tenou; blocked; slip (or lock); end grain to side grain; and side grain to side grain the side-grain-to-side-grain joint was least affected by cyclical high-low humidity exposure, and the block corner joint showed the greatest deterioration (Fig. 2.2). Of the adhesives evaluated, resorcinol and phenol-resorcinol generally performed best. Animal glue and casein glue were in the upper range on side-grain-to-side-grain joints but were generally the best durable in other types of joints. Acid catalyzed phenol and Urea Resin glues were generally intermediate in most joints, although there was considerable variation in the performance of the three Areas included in the study. Polyvinyl emulsion adhesive performed well in dowel and slip or lock joints but poorly in side-grain-to-

side-grain joint[25]. (Selbo, 1975)



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Figure 21—Various types of furniture joints used in a study on effect of joint design and exposure on the performance of different types of glues: A, Dowel; B, *mortise and tenon*; C, blocked; D, slip (or lock); E, end grain to side grain; F, side grain to side grain.



M 138 928

Figure 22—Comparison of percentages of control strength values retained by different types of assembly joints after 36 months of exposure to a repeating cycle *consisting of 4 weeks in air at 90 percent relative humidity followed by* 4 weeks in air at 30 percent relative humidity, both at 80° F. (Two different commercial animal glues were tested, and urea adhesives from three different manufacturers were tested.)

In the performance of two types of joints in two levels of exposure, under the humidity exposure of 65-30 percent and 90-30 percent for normal interior furniture exposure at 65-30 humidity,

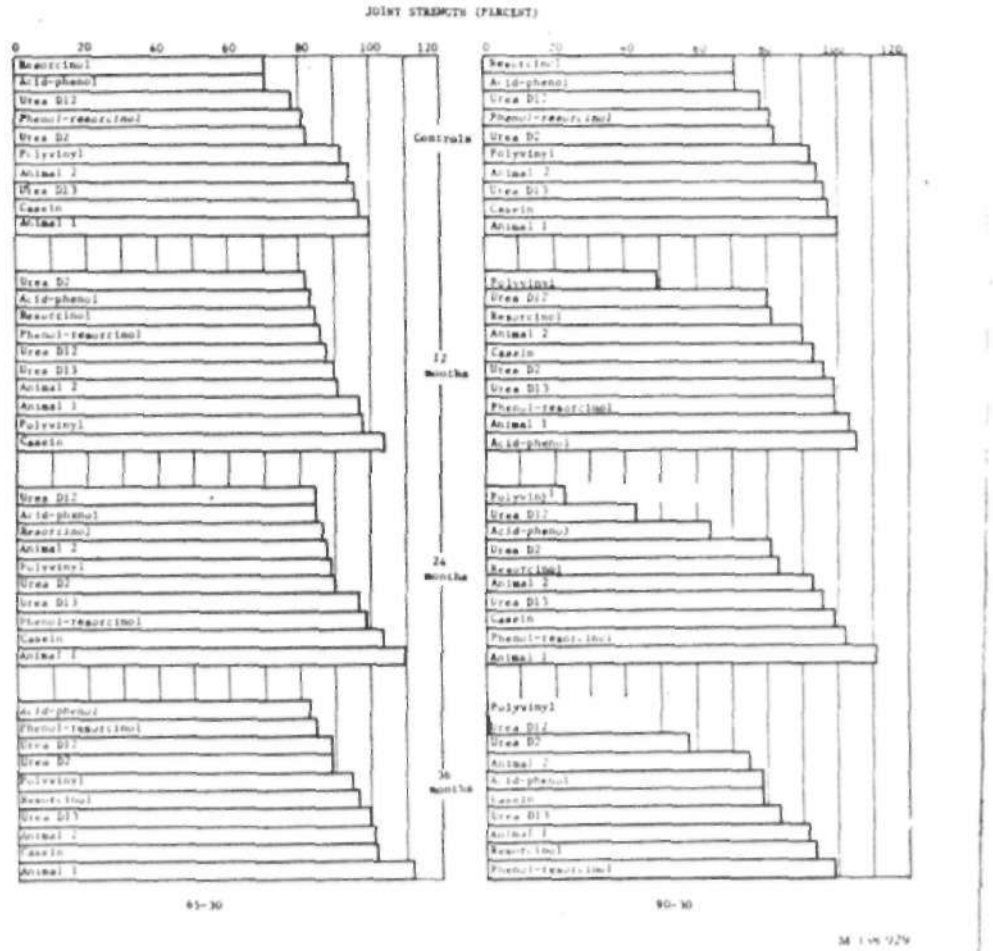


Figure 23—Performance of various glues in side-grain-to-side-grain joints exposed to repeating cycles between 65–30 and 90–30 percent relative humidity, all at 80° F.

side-grain-to-side-grain joints held up well with all glues. Where the grain was crossed, however (mortise and tenon Fig. 2.4), the casein glue (and others) deteriorated appreciably in the milder exposure and seriously in the more drastic humidity changes. The evaluation tests were made on sugar marble (soft wood) without any finish or surface coating and no load was applied during cycling. The evaluations also confirmed that Urea

resin is probably the most widely used adhesive for furniture. For moist and tropical condition, boil-proof adhesives such as Resorcinol and Phenol-Resorcinol would provide the best long-term performance.

Polyvinyl Resin emulsions, because of their flexibility, performed well in certain types of joints (e.g. Dowel, Slip or lock joints) Polyvinyl Resin emulsion was found to creep in joints with continuous stress and their moisture Resistance is low, thus unsuitable where high humidity prevails[25] (Selbo, 1975).

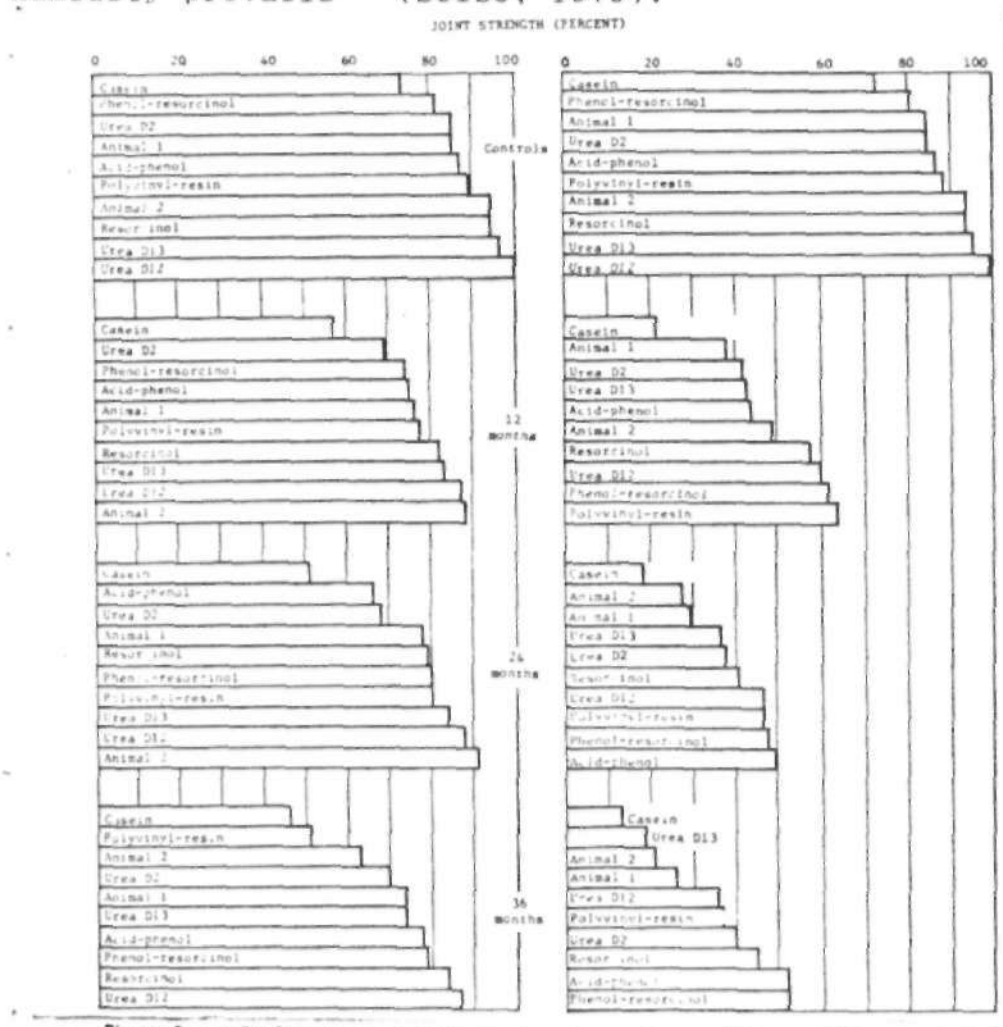


Figure 2-4—Performance of various glues in mortise-and-tenon joints exposed to repeating cycles between 65–30 and 90–30 percent relative humidity, all at 80° F.

Bryan H. River, Forest Products Technologist reports the classification of U.S. and some Imported woods according to ease of bonding (the bonding properties of selected wood species), based on the average quality of side-to-side-grain joints of lumber (of average density for the species) determined in Laboratory tests or based on industrial experience. The Laboratory tests included animal, casein, starch, Urea formaldehyde, and resorcinol formaldehyde adhesives.

River explained that woods which are difficult to bond satisfactorily with one adhesive type may bond more easily with another, depending on their chemical and rheological harmony. Adhesive manufacturers are able to formulate special adhesives to solve specific wood bonding problems[22] (River, 1987).

TABLE 2-1 CLASSIFICATION OF SELECTED WOOD SPECIES ACCORDING TO EASE OF BONDING

U.S Hardwoods	U.S. Softwoods	Importedwoods	
BOND EASILY[1]			
Alder	Fir:	Balsa	Hura
Aspen	White	Cativo	Purple heart
Basswood	Grand	Courbaril	Roble
Cottonwood	Noble	Determa[2]	
Chestnut, American	Pacific		
Magnolia	Pine:		
Willow, black	Eastern white		
	Western white		
	Redcedar, Western		
	Redwood		
	Spruce, Sitka		

BOND WELL[3]

Meranti(lauan):
Butternut
ELM:
American
Rock
Hackberry
Marple, Soft
Sweetgum
Seycamore
Tupelo
Walnut, black
Yellow-Poplar
Douglas - Fir
Larch, Western[4]
Pine:
Sugar
Ponderosa
Redcedar, Eastern
Afrormosia
Andiroba
Angelique
Avodire
Banak
Iroko
Jarrah
Limba
Mahogany:
African
American
Lightred
White
Yellow
Obeche
Okoume
Opepe
Peroba rosa
Sapele
Spanish-cedar
Sucupira
Wallaba

BOND SATISFACTORILY[5]

Ash, White
Beech American
Birch:
Sweet
Yellow
Cherry
Hickory:
Pecan
True
Madrone
Maple, hard
Oak:
Red[2]
White[2]
Alaska-Cedar
Port-Oxford-cedar
Pine, Southern
Angelin
Azobe
Benge
Bubinga
Karri
Meranti
(lauan), dark red
Paumarfim
Parana Pine
Pine:
Carribean
Radiata
Ramin

BOND WITH DIFFICULTY[5]

Osage-Orange
Persimmon
Balata
Balau
Green heart
Kaneelhart
Kapur
Kuruing
Lapacho
Lignum-Vitae
Rose-wood
Teak.

---

1. Bond very easily with adhesives of a wide range of properties and under a wide range of bonding conditions.

2. Difficulty to bond with phenol-formaldehyde adhesive.

3. Bond well with a fairly wide range of adhesives under a moderately wide range of bonding conditions.

4. Wood from butt logs with high extractive content are difficult to bond.

5. Bond satisfactorily with good-quality adhesives under well-controlled bonding conditions.

6. Satisfactory results require careful selection of adhesives and very close control of bonding conditions; may require special surface treatment.

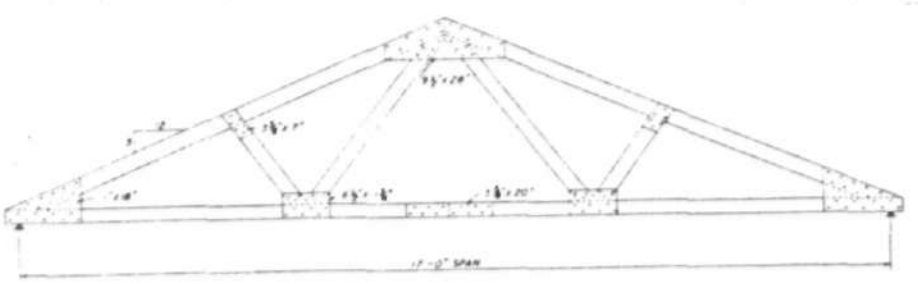
SOURCE[22]: Forest Laboratory. 1987. Wood Handbook: Wood as an Engineering Material Agriculture 72. Revision Washington, DC: U.S. Department of Agriculture PP.9-4,5.

In ship and boat component production, such as laminating assembly gluing, phenol-resorcinol adhesives are used almost exclusively. Rustproof screws or bolts are generally used for applying gluing pressure in assembly gluing of boats.

For laminated ship and boat members white oak (in America) is often used because of its high impact resistance and durability. White oak is a high density specie and thus requires high quality adhesive, generally of the phenol-resorcinol type. Sufficient assembly period is allowed for viscosity of the glue to build up to proper level. Elevated temperatures, about 150°F(66°C) are often required for curing for about 6 hours and at lower curing temperature, the curing period is extended.[23]

Housing components such as trusses and wall and floor sections have been factory made for many years. Because of adverse exposure that often occur during transportation (shipment) and erection, a waterproof adhesive; resorcinol or phenol-resorcinol is often recommended for gluing of such

components. Housing components are usually a combination of lumber and plywood, thus appreciable stresses on the joints with seasonal moisture changes are almost unavoidable. This is another reason for advocating highly durable adhesives for housing component manufacture. Forest Laboratory has devised various means of pressing and curing the glue joints in components. Low-voltage heating and nail pressure are common methods. Various types of clamps are also commonly used. Nails are often used in fairly fluid adhesives. No general rules are developed for relating nail size and spacing to ensure adequate pressure.[25]



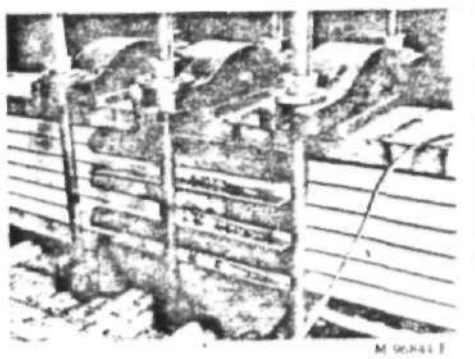
ZM 96227 F

Figure 2-5—Light truss with plywood gusset plates glued to framing members. The gussets were ½-inch, five-ply, exterior-grade Douglas-fir plywood; framing members were 1⅝ by 3⅝ inches in cross section; and ninepenny nails (indicated by + on sketch) were used to apply gluing pressure.



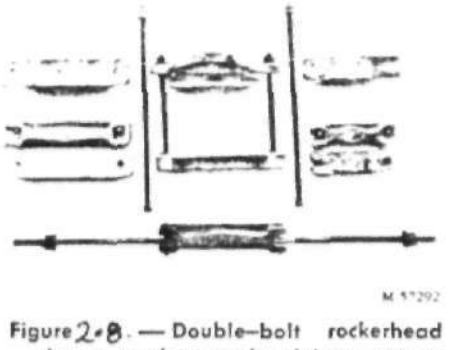
M 90445 F

Figure 2-6—Curing glue in scarf joints with low-voltage electric heating. The heating elements are embedded in silicone rubber pads and aluminum foil separates the pads from the boards to prevent contamination of the pads by glue squeezeout.



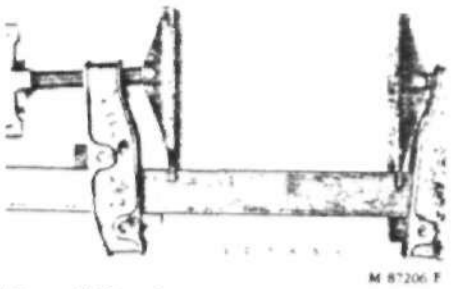
M 90444 F

Figure 2-7—Curing phenol-resorcinol in scarf joints with continuous rubber pad heated with low-voltage electric current. Thin sheets of aluminum separate pad from boards to prevent contamination of pad by squeezed-out glue.



M 57292

Figure 2-8. — Double-bolt rockerhead clamps used to apply gluing pressure to laminated assemblies. The rockerhead equalizes the pressure across the assembly.



M 87206 F

Figure 2-9 —C-type rockerhead clamp with adjustable span used for laminating and other gluing pressure applications.

Production of laminated glued wood products suitable for unprotected exterior use dates back to the development of resorcinol and phenol-resorcinol adhesives about 1943. Glues available before that time either lacked necessary water resistance or required very high curing temperatures such as those used for exterior-type plywood.

To impart durability to the wood bonded joint under exterior service, however, preservative treatment is sometimes required. In some instances, the laminations are treated before gluing, and this necessitated development of procedures for bonding preservative-treated wood.

Preservative-treated structures can also be produced by treating the glued members, and an example is a "Bridge on

logging railroad near Longview, Wash., built with laminated stringers pressure treated with Creosote-Oil mixture before erection". Bridge timbers produced by this method have been found to be in excellent condition after more than 25 years of service.

Of the two methods, treatment after gluing has been most used. However, when laminated members do not lend themselves to treatment because of their size and shape, gluing treated material is the only known method to produce adequately treated members.

Studies on gluing of wood treated with wood preservatives and fire-retardant chemicals were undertaken during the latter part of the World War II and years that followed.

The 60-foot, open deck bridge trestle on Atlantic Coastline Railroad South of Palmetta, Fla. Lumber used in stringers was treated with fluor-chrome-arsenate-phenol (Wolman salt) before gluing. The stringers on the opposite side of the trestle were glued from creosote-treated southern pine. This type of material was glued commercially as early as 1945.

Data show that certain combinations of glue and preservative treatments are compatible under prescribed conditions of gluing, whereas others require further study both on laboratory and commercial scale before definite production procedures can be formulated. The advice of the glue manufacturer should be sought before gluing wood treated with a particular preservative.

In general, somewhat more curing (higher temperature or longer time) is required when gluing treated than untreated wood.

Gluing of treated lumber also like the untreated lumber requires reasonably clean joint surface before bonding, similarly treated lumber involves surfacing after treating (preferably shortly before gluing) is required. Where the glued members are intended to withstand exterior exposure, the joints should pass the tests prescribed in Voluntary Product Standard PS56-73 for structural glued laminated timber. For interior service joints a test is to ensure resistance to termites and similar hazard and from the weather.

As a general rule, woods that take treatment well, such as southern pine, can also be glued satisfactorily.

Treating large laminated timbers with water borne preservatives after gluing is generally not recommended because of checking and dimensional changes that occur during drying[27]. (Selbo, 1975)

White[28] (1975) assessed durability of a wide range of phenolic and Amino-plastic adhesives (selected in 1954-62) in Khaya and Beech plywood exposed to weather in the U.K. and to cyclical or continuous exposure in a controlled environment 27°C 87% Relative humidity (R.H.) and/or 35°C 30% R.H. for 10-17 years. Only phenolic resins with little or no filler content are recommended for use under severe exposure conditions. The paper informs that plywoods made with fortified Urea-formaldehyde (UF), Melamine - Formaldehyde (MF) or MF/UF mixtures were more durable in severe environments than were conventional UF-bounded boards. Plywood durability depended markedly on wood species, unprotected

Khaya having a life of 15-20 years, whereas Beech plywood began to deriorate after 5-7 years' exposure.

White[26], also discovered in his research Laboratory work that durability was greatly increased by protective coatings of paint, varnish or creosote.

The Laboratory research work of U.S. Department of forest services sums up the performance of mechanical properties of bonded joints like joint strength, joint rigidity, panel bending strength, or bending stiffness is eavaluated at short term and long term.

In short term, the properties of wood, adhesives, and bonded products decrease as the temperature or moisture level increases. Strength and rigidity or stiffness may return to their original levels if the yield point of the material has not been exceeded while under load.

The short-term performance of joints and products made with rigid adhesives like resorcinol-formaldehyde, Phenol-formaldehyde, Melmine-formaldehyde, and Urea-formaldehyde which change less than wood, is simply evaluated by tests at room temperatures, dry and wet. Casein, Polyvinyl acetate, and elastomer-base which change more rapidly than wood, are tested dry (or dry after soaking) and after exposure to high humidity environments. Some special cases such as may occur in roofs, require testing of bonded structural products at elevated temperatures. Laminated beams and plywood require fairly high minimum strength and wood failure values after several different

water exposure tests.

In the long term, wood, adhesives, and bonded products degrade at a rate determined by the temperature and moisture levels, the concentration of certain chemical which can have serious effects, the presence of micro-organisms, and the stress level. Long-term performance is equated with the ability of a joint or product to withstand these factors. Resistance is measured by the loss or rate of loss of a mechanical property against the time of exposure.

Joints well designed and well made with any of the commonly used wood working adhesives will retain their strength indefinitely if the moisture content of the wood does not exceed approximately 15 percent and the temperature remains within the range of human comfort. However, some adhesives deteriorate when exposed either intermittently or continuously to temperatures much above 100°F (38°C) for long periods. Low temperatures seem to have no significant effect on strength of bonded joints.

Joints and products that were well made with phenol formaldehyde, resorcinol formaldehyde, or phenol-resorcinol formaldehyde adhesives have proved more durable than the wood when exposed to warmth and dampness, to water, to alternate wetting and drying, and to temperatures sufficiently high to char the wood. These glues are entirely adequate for use in products that are exposed indefinitely to weather.

Joints and products well made with melamine formaldehyde, melamine-Urea formaldehyde, and Urea formaldehyde resin adhesives

have proven less durable than wood. Melamine formaldehyde is only slightly less durable than phenol formaldehyde or resorcinol formaldehyde and is still considered acceptable for structural products. Melamine - Urea formaldehyde is significantly less durable, and Urea - formaldehyde is quite susceptible to degradation by heat and moisture.

Joints or products bonded with polyVinyl acetate, hot melts, and natural resins will not withstand prolonged exposure to water or high moisture content, or repeated high-low moisture content cycling in bonds of high-density woods. However, if they are properly formulated these adhesives are durable in a normal interior environment.

At present it appears that some isocyanate, epoxy, and cross linked polyVinyl acetate adhesives are durable enough to use on lower density species even under exterior conditions.

Estimate of long-term performance are also (apart from accelerated laboratory exposures) obtained by placing specimens in out door exposure for 1 to 20 years. Out-door exposures are intensified by facing the specimens south at an angle perpendicular to the noonday sun and by exposing the specimens without protective covering or coating.

Treatments that can be used to increase the durability of glued products include:

(1) Coatings that reduce the moisture content changes in the wood and

(2) Impregnation of glued members with preservatives,

particularly those that will also prevent rapid moisture changes and deteriorating effects of prolonged exposure to outdoor or damp conditions can be greatly reduced[22]. River (1987).

The West African Building Research Institute in 1959 carried out three exposure tests at three sites in Nigeria using samples bonded with several types of cold-setting assembly glue, the specimens were subjected to a variety of degrees of exposure. The only glues which remained entirely sound after five (5) years exposure were the Resorcinol and phenolic resin glues. Other varieties; Urea and melamine resins, caseins and animal glues showed some degree of breakdown even though they were exposed within ventilated buildings. Resorcinol glues were also found very effective when components were glued after pressure treatment with preservatives. Also the glues were widely used in boat-building Industry in West Africa[27] (TYLER, 1962).

From the foregoing literature review, it is clear that for wood jointing, thermosetting adhesives are more frequently used and the commonest types are Phenol and Resorcinol formaldehyde; Urea and Melamine formaldehyde; polyvinyl acetate and copolymer emulsions[7] for their strength and durability.

Common adhesives manufactured here in Nigeria (locally) are cascamite powdered synthetic resin, emulsions of: ponal; pronel; dunlop; climax; Amaga, Armens etal. From an inquiry of durable structural glues commonly available and used in Nigeria from Saint Joseph Technical College Makurdi (former site for boat-

building during the British rule and by early 1960s), Government Technical College Makurdi; Savannah Forestry Research Centre, Samaru-Zaria, Nigerian Civil Aviation Centre Zaria (Civil Engineering Department), Industrial Training Centre, Samaru-Zaria, and the carpentry units of Civil Engineering Department and Building Department of ABU Zaria, I was told that the best structural glue used in Nigeria is cascamite powdered synthetic resin glue, seconded by ponal emulsion resin glue. The above was confirmed by me by a preliminary laboratory test of the gluability of mahogany with cascamite and ponal emulsion glue.

This study therefore employed cascamite powdered synthetic resin, thermosetting adhesive because of its moisture resistant, moderately weather resistant and its durable qualities over the other local adhesives. Mahogany (Khaya-Senegalensis) was also chosen for its availability and wide usage in structural engineering works in this part of the country (Northern Nigeria).

2.2 FLEXURAL (BENDING) MEMBERS

Resorcinol glues were used at the West Africa Building Research Institute Accra, Ghana and Zaria, Nigeria by 1962 in the fabrication of joints in rough - sawn hardwoods for both trusses and beams and very efficient joints were obtained and the glue was found to cost 2/- (two shillings) per square foot of surface joined, then. The Institute on the basis of efficiency of resorcinol glued joints components adviced and these glues were used for laminated parabolic arch ribs for experimental

greenhouse at the West African Cocoa Research Institute at Tafo, Ghana. Also ribs which were fabricated in Mansonia, air seasoned to 13 percent moisture content were in good conditions after 2 years and were subjected to diurnal temperature range of 21-66°C and high relative humidities. (Tyler, 1962.)[27]

Glued - Laminated or parallel - grain construction are used as in doors or tabletops and other furniture panels, seats, bench tops structural beams and arches, boat timbers, deckings, airplane propellers, spars, spar flanges, baseball bats and bowling pins.

2.3 TENSILE MEMBERS

To obtain acceptable strength in pieces spliced together endwise, it is necessary to make a scarf, finger, or other sloped joint.

Tests on specimens, from Forest Products Laboratory Madison, containing scarf joints stressed in tension indicated the average strength ratios given in table 2.2.

Table 2.2 Scarf Joint in Tension Parallel to Grain

Slope of Scarf	Strength ratio Jointed/non jointed Percentage (Pct)
1:12 and less Steep	90
1 in 10	85
1 in 8	80
1 in 5	65

The Approximate tensile strength (expressed as a percentage of clear wood) of various types of end joints (end butt, finger and scarf joints are shown in fig. 2.10.

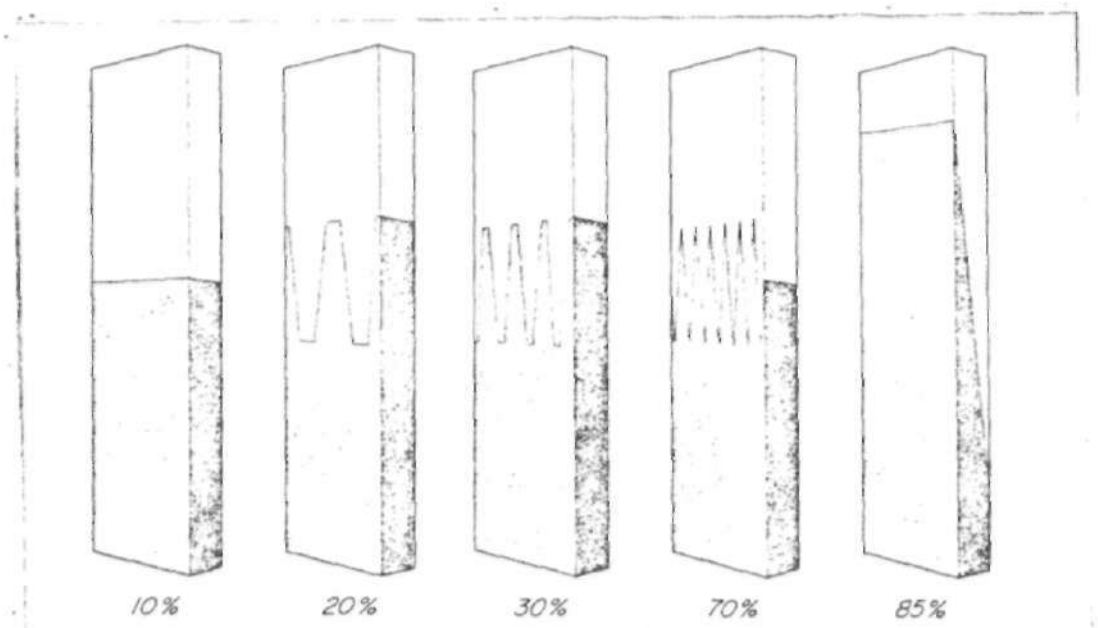
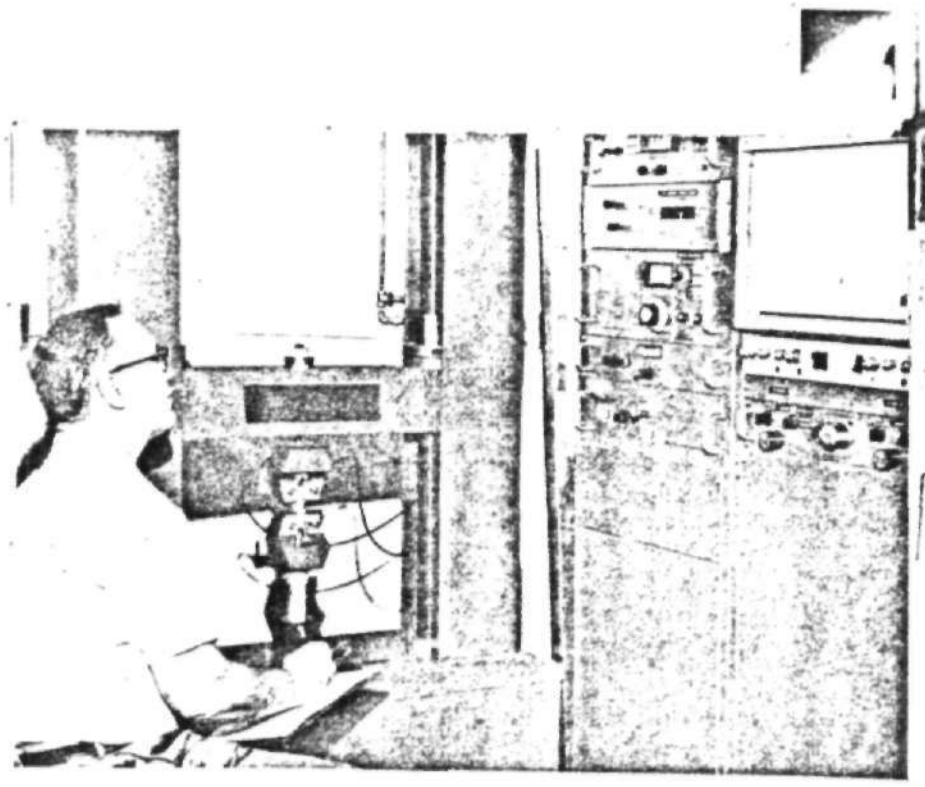


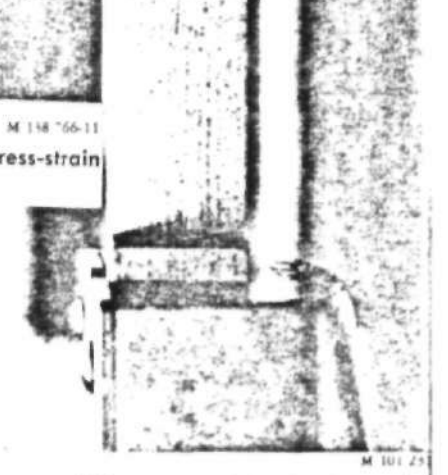
Figure 2.10—Approximate percentage of the tensile strength of clear wood obtainable with different types of end joints. (Nearly the full tensile strength of a low-density species has been obtained with butt joints in laboratory experiments but no practical glue or gluing procedure have been developed to do this commercially.)

Tension test are reported by the madison forest Laboratory as been generally considered the most reliable for glued end joints. A rectangular specimen shown in figure 2.11 is easily prepared and rapidly tested.



M 138 766-11

Figure 2.11b—Electronic universal testing machine capable of plotting stress-strain curves.



M 101 25

Figure 2.11a—Finger-jointed strip-tension specimen in test grips for testing.

Forest products Laboratory reports that not more than 25 percent of the tensile strength of the wood parallel to grain can be achieved in end-butt joint using conventional water-based adhesives. The Laboratory derived a general rule for joints strength to approximate tensile strength of solid wood, a scarf, finger, or other type of joint that approaches as closely possible as parallel to grain direction (a side-grain surface), the side grain area should be at least 10 times as large as the cross-sectional area of the piece. It was explained that it is because Wood is approximately 10 times stronger in tension than in shear[22]. (River 1987).

2.4 SHEAR - TENSION MEMBERS

A glued joint should never be subjected to direct tension alone in a direction at right angles to the plane of the contact surface. In a plain scarf joint subjected to a tension force, the stresses on the glue line may be resolved into shear and tension component. The steeper the scarf joint, the larger the tension stress at right angles to the glue line, and consequently the efficiency is reduced[7]. (Booth and Reece 1967).

In a lap glued joint, the thick glueline transfers tensile force from one stick to the other through shear stress. At each end of the glue line where the shear stress peaks, with both sticks sharing the tensile force equally where they over lap[14]. (Kubler, 1980).

In block shear glued joint tests, the U.S. forest Product

Laboratory considered wood of various species glued with casein, Urea resin, and phenol-resorcinol resin. The joints were about as strong as the wood; with casein, a large percentage of the failures in the denser species were in the glue, indicating that the glue bond was the weakest link. Well made casein glue joints will develop full strength of most low and medium-density woods in shear parallel to grain and would retain a large part of their strength even when submerged in water for a few days. With dense woods, however, casein glue develops only medium to low wood failure percentages. (Selbo 1975)[25].

Douglas and Pettifor, 1932, carried out tests on simple lap joints. The Analysis of the results indicates that when the lap joint was subjected to shear by the action of the force P, the apparent mean shear stress at failure obtained by dividing the load P by the area of the contact surface is not constant for a given adhesive or species of timber but varies approximately:

(i) as the square root of the thickness t and

(ii) inversely as the length of the overlap l.

This suggests that the shear stress is distributed not uniformly but in some complex manner over the area of the contact surface as illustrated in deBruyne's experiement, 1945.
de Bruyne in a working model of a lap joint made by sewing two pieces of elastic tape together with elastic thread. If the two ends of the tapes are pulled apart it will be found that the threads at the extremities of the lap are stretched more than at the centre, indicating that the effective shear stress varies

from a minimum value at the centre to a maximum at the two ends of the lap. Utilising Volkersen's analysis of the strains in an idealised riveted joint de Bruyne showed that a pull at the ends of the tape is similar to shear stress distribution across the lap joint and marked concentration of stress at the ends[21].

In a curve drawn from test results of beech specimens in which the apparent mean shear stress has been plotted for values of $\sqrt{t}/l$. The values of $\sqrt{t}/l$ and the apparent mean, μ, ranging from zero to 0.50 was noticed to be a straight line and the equation

$$\mu = \frac{V'\sqrt{t}}{l} \text{ developed.}$$

The equation was modified and adopted for a rule suggested for the design of lap joints:

$$\mu' = \frac{3V\sqrt{t}}{t}$$

where

μ' = Permissible working stress in mean shear i.e stress which when multiplied by the area of the contact surface will give the safe working load on the joint exposed to normal service conditions for long periods. (should not exceed 1.5V).

μ = Apparent mean shear stress at failure in N/mm^2

V = Basic working stress in shear parallel to the grain. Tablelated for timber grade names.

V' = A constant determined experiementally for the species of timber used.

t = The thickness of the member in mm and

l = The length of overlap in mm.

(Reece 1949)[21]

Timber Research and Development Association under Prince Risborough Laboratory in London in the 1960s (Chugg and James 1965) investigated the gluability of a number of hardwoods. Five types of structural adhesives were employed in the trials, these included a casein (INT), three resins (WBP), and an Urea-Fomaldehyde (MR). The investigation was on the basis of the requirement that no significant difference should be noted between the shear strength of the glue line and that of the timber itself.

The investigation confirmed an observation made in previous research at the Princes Risborough Laboratory, that the strength of glued joints in shear parallel to the grain increases with an increase in density of the timber upto 750kg/m^3, after which no further increase in shear strength occurs, the performance becoming limited by the strength of the glue line itself[15]. (Mettem 1986).

2.5 EFFICIENCY RATINGS OF GLUED END JOINTS IN SOFT WOOD

Table 2.3 lists efficiency ratings for some common profiles of figer joints manufactured in accordance with B55291[6]. The efficiencies given apply only to joints with profiles visible either on the face or edge of rectangular sections, provided that at least four complete fingers are present[6].

Table 2.3 Efficiency Ratings Of Some Finger Profiles

Finger Profiles			Efficiency rating in bending and Tension parallel to grain	Efficiency rating in compression parallel to grain
Length	Pitch	Tipwidth		
mm	mm	mm	%	%
55	12.5	1.3	75	88
50	12.0	2.0	75	83
40	9.0	1.0	65	89
32	6.2	0.5	75	92
30	6.5	1.5	55	77
30	11.0	2.7	50	75
20	6.2	1.0	65	84
15	3.8	0.5	75	87
12.5	4.0	0.7	65	82
12.5	3.0	0.5	65	83
10	3.7	0.6	65	84
10	3.8	0.6	65	84
7.5	2.5	0.2	65	92

Source[5]: Table 104 of BS 5268: Part 2: 1984
Appendix F. PP 101.

Table 2.4 lists efficiency ratings for plain glued scarf joints in individual laminations (same for lumber piece) in glued laminated softwood graded in accordance with BS 4978 and manufactured generally in accordance with BS 4169.

Table 2.4 Efficency Ratings of Plain Glued Scarf Joints in Individual Laminations in Laminated Softwood

Lamination Grade	Scarf Slope	Efficiency Rating in bending and tension parallel to grain	Efficiency rating in compression parallel to grain
		%	%
	1 in 6	69	100
LA	1 in 8	77	100
	1 in 10	84	100
	1 in 12	88	100
	1 in 6	67	100
LB	1 in 8	75	100
	1 in 10	81	100
	1 in 12	85	100
	1 in 6	50	80
LC	1 in 8	65	95
	1 in 10	68	100
	1 in 12	72	100

Sources[5]: Table 105 of BS 5268: Part 2: 1984
Appendix F. PP 101.

CHAPTER THREE

3.0 SAMPLE PREPARATION AND TEST PROCEDURE

Procedures for test on small clear specimens of timber have been standardized, however for the purposes of this study, the specifications of these standards have been modified to suit the near live Nigerian timber sizes to give data for glued mahogany joint specimens comparative with near live clear timber specimens. The modified standards include B.S. 373: 1957, B.S. 1204: part 2: 1965, B.S. 5291: 1984, B.S. 5268: parts 2: 1984, standard testing procedure - Forest Products Research Laboratory, Ibadan, Nigeria 1965, American Standards of Testing Material (A.S.T.M) D897-49, D1184-55, D905: part 6: 1958.

Testing and Inspection of Engineering materials, Davis, et al., 1964 and reports from Forest Products Research Laboratories Madison (U.S.A) and London (U.K) were also utilized for the same purpose.

3.1 SELECTION OF SAMPLES

Timber of three sizes: 150 x 50mm, 100 x 50mm, 75 x 50mm were obtained from Zaria timber market in two batches (all were mahogany species supplied from the Savannah dry-zone of Zaria, Kafanchan, Zonkwa, Kagoro, Minna, Saminaka, Kaduna and Abuja).

3Kg tin of cascamite powdered resin glue was supplied in a single batch in good condition.

universal testing machines available in Civil Engineering

and Mechanical Engineering material testing Laboratories were adapted for the experiments. The sizes of the specimens were modified or standardized (improved) to suit the facilities available and the standard ratio of le/b less or equal to 15 was used.

3.2 LABORATORY TESTS

3.2.1 MOISTURE CONTENT AND DENSITY DETERMINATION

Wood is hygroscopic; so its (imbibed) moisture content tends to come to equilibrium with the surrounding atmosphere. Water has a profound influence on the properties of wood, affecting its weight, strength, shrinkage, and liability to attacks by some insects and by fungi that cause stain or even decay. The four common moisture content characteristics are green, 30 to 250 percent; air dry, 12 to 15 percent; Kiln dry; 6 to 7 percent; and oven dry, 0 percent.

Since the properties of timber depend so much on the amount of moisture it contains it is necessary to know the exact moisture content of a particular sample. The amount of moisture present in converted wood varies appreciably in different circumstances, but dry weight of wood substance in a given sample is constant.

There are several ways of determining the moisture content of wood, there are namely: By typical robust shrinkage frame apparatus, By Basic gravimetric techique, Distillation method (process), By electric moisture meters (electrical resistance).

Direct current or Alterative current, and oven-drying method.[13] Oven-drying method is the most satisfactory method for most purpose and has been adapted for this study.

Apparatus:

Avery universal weighing machine 30Kg capacity and Mettler Electronic weighing machine, Griffin 300F COVEN 300°C good ventilated oven and a good power supply (source of heat).

Sampling:

The mahogany supplied were stored in the Civil Engineering Laboratory, from which all the samples for the three experiments (Bending, Compressive and Tensile Strength Tests) were fabricated. The moisture content tests block; 75 Nos were cut off from the 75 number of specimens fabricated for the experiments. The moisture content specimens were clear, solid pieces (no Knots or splinters), about 30mm long in the direction of the grain and taken from the test specimens near the breaks.

Procedures:

The test blocks were rapidly weighed as soon as they were cut off from the main tested specimens; to

minimize the chance of samples picking up, or losing moisture between the time of cutting and that of weighing to avoid appreciable errors in calculating moisture content which could differ from that of the main crushed specimen. After the initial weighing the samples (specimens) were transferred to the Griffin 300F coven, 300°C standard ventilated oven. The specimens were spread in the oven chambers to avoid the central ones being sealed in, as a result of case-hardening. The temperature was then raised to 103 ± 2°C through 60°C temperature for the first few hours to prevent caking. The specimens were left over night and re-weighed after 24 ± 2 hour until dried to a constant weight. The first oven drying test witnessed a lot of removing and weighing after 24 hrs from first weighing to arrive at a correct constant dried weights of specimens. The loss in weight expressed as a percentage of the final oven-dry weight is taken in this study as the moisture content of the test piece.

Conclusion:

Percentage - moisture content = weight of sample at test in grammes minus oven-dry weight of sample in grammes per oven-dry weight of sample in grammes expressed by 100%

$$= X = \frac{W_1 - W_0}{W_0} \times 100\%$$

Single calculations of moisture content may be sufficient for determining whether a stack of timber is suitable for a general purpose, example (e.g.), indoor or outside use, but an occasion can arise when it is desirable to determine moisture contents of the same material from time to time over a period. This is a case for example, when studying the progress of seasoning in a stack. Results of the moisture contents of various samples are in Tables 4.4, 4.5 and 4.6.

DENSITY

For the determination of density the compression parallel to grain test specimens are used. The specimen is weighed and its volume obtained by measuring the length, breadth and thickness of the specimen. The density is expressed as the ratio of the weight of specimen at test to its volume.

SPECIFIC GRAVITY

All test specimens were weighted and their dimension determined before test. The specific gravities at test and when oven-dry were calculated for each tests specimen. The 30mm specimens used for the determination of moisture content were subsequently used for the determinate of specific gravities.

Data:

W_1 = weight of specimen at test in grammes.

W_0 = weight of specimen, oven-dry, in grammes.

V_1 = volume of sample at test in cubic centimetres.

L = Length in millimeters

b = Breadth in millimetres

h = Height in millimeters

Specific gravity at test, S_1,

$$S_1 = \frac{W_1}{V_1} \quad \text{or} \quad \frac{W_1}{Lxbxh} \quad Kg/mm^3$$

Nominal specific gravity, oven-dry, S_0.

$$S_0 = \frac{W_0}{V_1} \quad \text{or} \quad \frac{S_1 \times 100}{x + 100}$$

where X is the percentage moisture content.

The calculated values of density and specimen gravity of specimen are found in Table 4.7.

3.2.2 FLEXURE (STATIC BENDING) WOOD TEST PARALLEL TO GRAIN

OBJECT:

To determine the mechanical properties of wood/glued wood subjected to bending, to observe the behaviour of the clear and glued mahogany joint specimens under load, and to study the failure. The specific items to be determined were:

1) Fibre stress at limit of proportionality

2) Equivalent fibre stress at ultimate/maximum load (modulus of rupture)

3) Modulus of elasticity

4) Type of failure

5) Efficiency of glued pieces

SPECIMEN:

Clear wood; 5 Nos of 700x145x50mm, 10 Nos of 700x145x50mm Finger glued joints (three (3) different types of fabrications), 9 Nos of 700x145x50mm Scarf glued joints (in 3 slopes), and 3 Nos of 700x145x50mm Partial integral glued joints. All specimens were fabricated from the Nigerian lumber size of 150 by 50x3600mm. The joints were fabricated with Nigerian structural cascamite powdered synthetic resin glue under laboratory room temperature (standard) conditions of 20±3°C and humidity (relative) of 65±2%.

Special Apparatus:

Dial gauge (Deflector), beam supports steel solid rollers and metal plates, and loading blocks.

Procedure:

The static bending test was carried by the four point method.

Each specimen was measured and weighed.

the centre and the overhang of the beam were marked, overhang taken as, d, (145mm) and span left (end points) as 410mm. right section lines through these points were drawn using square. The position of loading blocks; tops were marked span/6 (68mm) from the end support. The specimen was then set in position such that it will be subjected to a uniform bending moment over a considerable portion of its length and

the strength required can be calculated without the necessity of allowing for shear deflection which occurs along the whole length of a beam loaded at the centre. The orientation of the annual rings for the test pieces were such that they were parallel to the direction of the loading, and the test pieces were supported (suspended) at the ends in such a way that they were quite free to follow the bending action and were not restrained in any form by friction which would resist the bending and tend to introduce longitudinal stresses. The deflectometer was set to read the deflections at the central portion of the beam.

The strain ganges were planted at the midspan of the specimen to the compression and tension faces by araldite glue and soldered to special strain cables and connected to 2 strain metres called strainometers.

The machine and the deflectometer (dial gauge) and the two strainometers were adjusted to read zero.

The load was applied at such a constant and slow speed; 20KN/13-15 seconds (1.33-1.54KN/sec) as to ensure static loading of the test piece.

Readings were taken simultaneously with simultaneous loads and increments of 20KN to give at least about 9 readings below the ultimate load. Readings recorded were deflection of the test piece at mid-length, measured with strain gauges fixed to the

compression and tension faces of the test pieces (from strainometers), dialguage (cross checking purposes) and most importantly the load from the Denison universal compression/Bending Test machine (250 tons capacity).

Failure mode of each specimen was recorded as loading continued until the sample failed.

Samples of 30 x 30 x 50mm moisture content test were cut from the specimens near the ruptured section for oven drying method.

Report:

The measured strains, together with the corresponding applied stresses were used to plot the stress-strain curve for each test piece. The data obtained in the experiment is used in computing the following properties:-

moisture content, fibre stress at limit of proportionality, equivalent fibre stress at ultimate load (modulus of rupture) the modulus of elasticity and efficiency of glued joint pieces. Summarized results are presented in Table 4.1.1.

Discussion:

Discussion and analysis of results are in Chapter Four. The dimensions of the test pieces, as well as the experimental set-up are shown in Fig. 3.1 and Plates 3.1, 3.2, and 3.3.

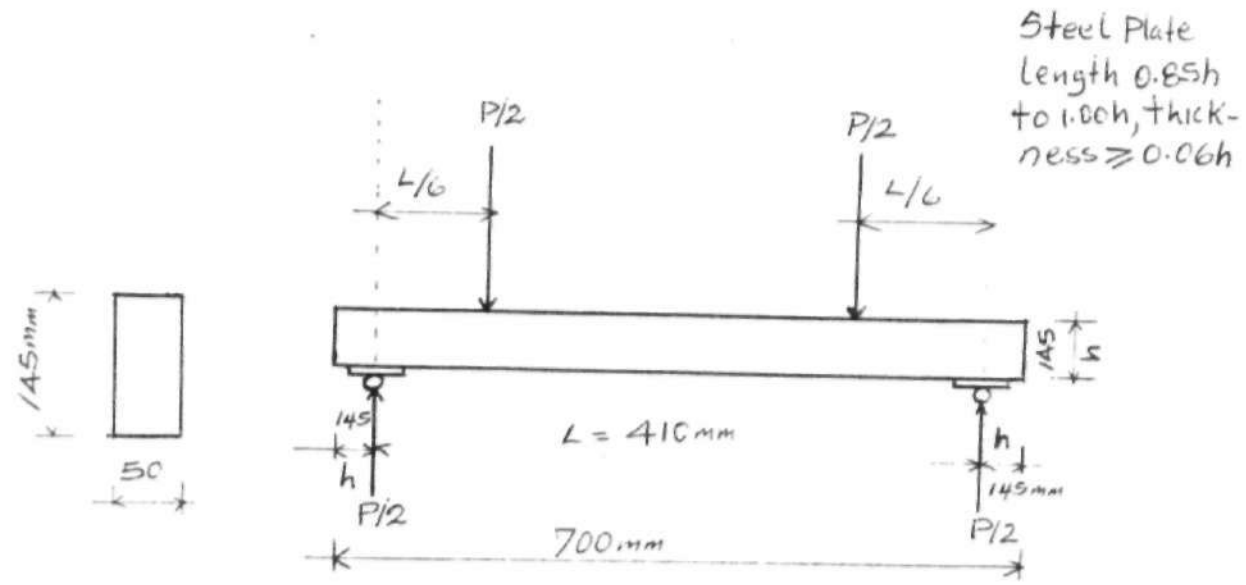


Fig. 3.1: Static Wood Test Piece



Plate 3.1: Static Bending Test. Experimental set-up

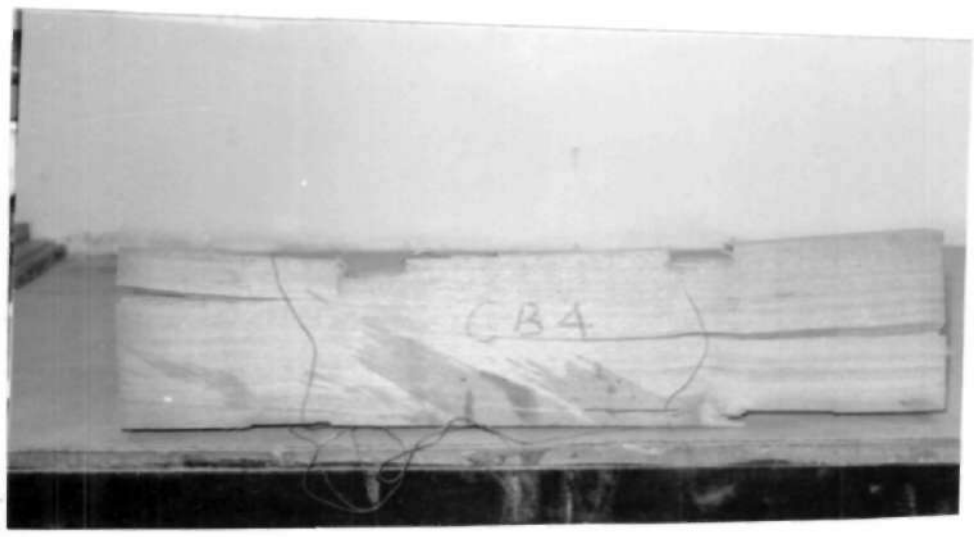


Plate 3.2: Static Bending Test, Experimental Marks.

3.2.3 TENSILE TEST OF WOOD PARALLEL TO GRAINS

The form, dimensions and experimental set-up of the tensile test parallel to grain test pieces are as shown in Figure 3.2 and Plates 3.4, and 3.5.

Object:

To determine some of the mechanical properties of wood and glued wood subjected to tensile load. That is to observe the behaviour of the clear and glued timber joint specimens under axial tensile load, and to study the failure pattern/modes. The specific properties to be determined were:

(1) Tensile stress at the limit of proportionality.

(2) The tensile stress at ultimate load.

(3) Mode of failure.

(4) Efficiency of glued pieces in respect to the clear pieces.

Specimens:

Clear wood; 4 Nos of 30 by 30 by 450mm and 4 Nos of single shear lap glued joints 30 x 30 x 450mm.

Special Apparatus:

4 Nos of 35mm space block clip holder (wedge grips), 2 Nos of machine setting, universal tensile "Avery machine" 100 tons capacity (capable of plotting strain-stress curves), 2 trainometers, connecting strain cables, strain-gauge, araldite and cascamite glue.

Procedure:

The ends of the specimen were cut square and smooth. The specimens were marked 100mm length from both ends for wedge grips and the strain gauges were planted at the middle of the test pieces on both faces by araldite and soldered to special strain cables which were connected to the strainometers.

The test piece was placed in the middle of the grip wedge blocks, thus the test piece was embedded in to the wedge grip by 100mm, on both ends.

The pieces were fixed firm and centrally to give axial load and to avoid eccentricity. The ends of the pieces were held in position by wedge grips to provide even distribution of the concentrated load at the ends

and to avoid crushing of the test pieces at the grips.

The load was applied to the 30 x 30mm face of the ends of the test piece through the special wedge grips.

The load was applied gradually on the 'Avery' tensile electronic machine which was also plotting the stress-strain curve.

The corresponding strains due to the loads were recorded/read from the strainometer from zero load to the failure load. The increase in load was regular and constant.

Failure modes of specimens were also recorded. A 30 x 30 x 30mm moisture content block was cut near the ruptured section of each test piece and dried in the oven until a steady weight was obtained.

Report:

The recorded strains together with the corresponding applied stress were plotted at the stress-strain curve for each piece.

The data obtained in the experiment is used in computing the following properties:-

Tensile stress at the limit of proportionality.

The tensile stress at ultimate load and,

Efficiency of glued pieces in respect to the clear pieces.

Summarized results are presented in Table 4.3.1.

Discussion:

Discussion and analysis of results are in Chapter Four.

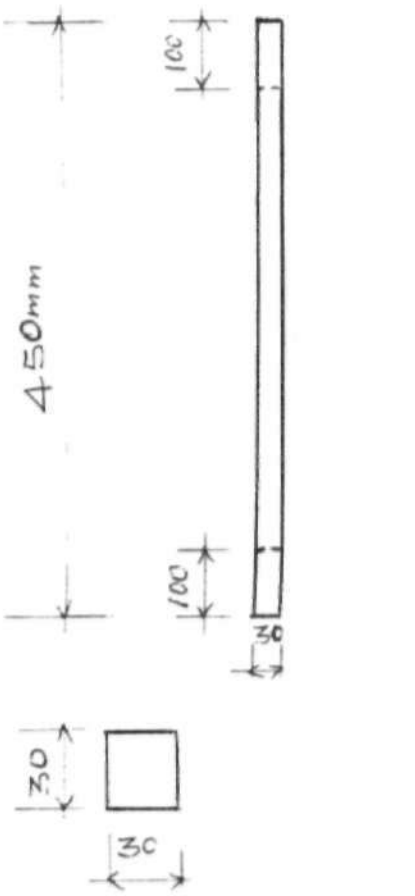


FIGURE: 3.2 SPECIMEN FOR TENSILE TEST PARALLEL TO GRAIN.

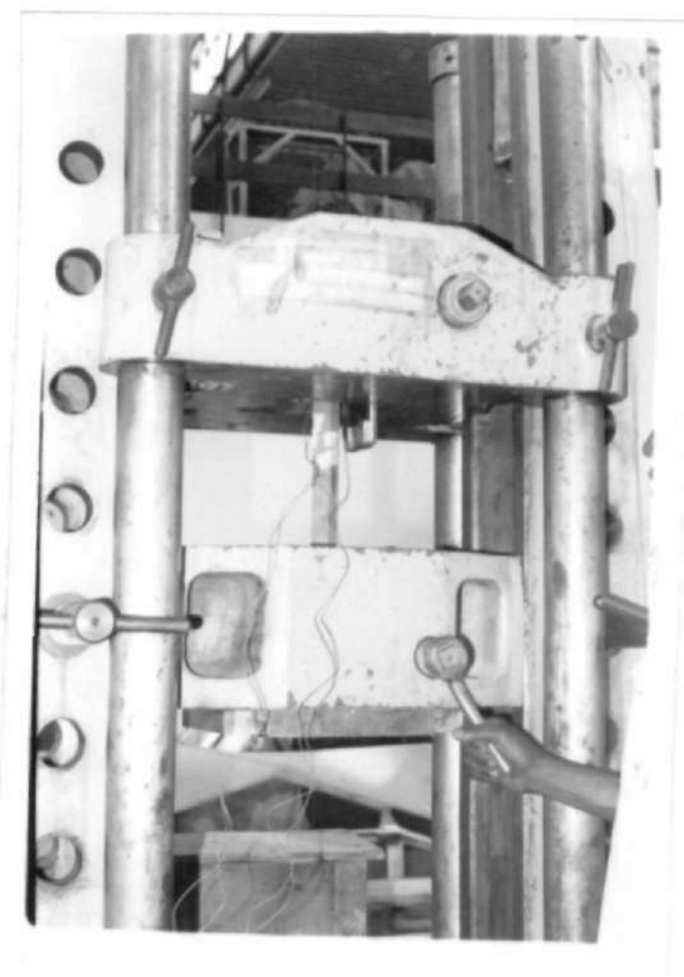


Plate 3.4: Tension Test Parallel to Grain Experimental Set-Up

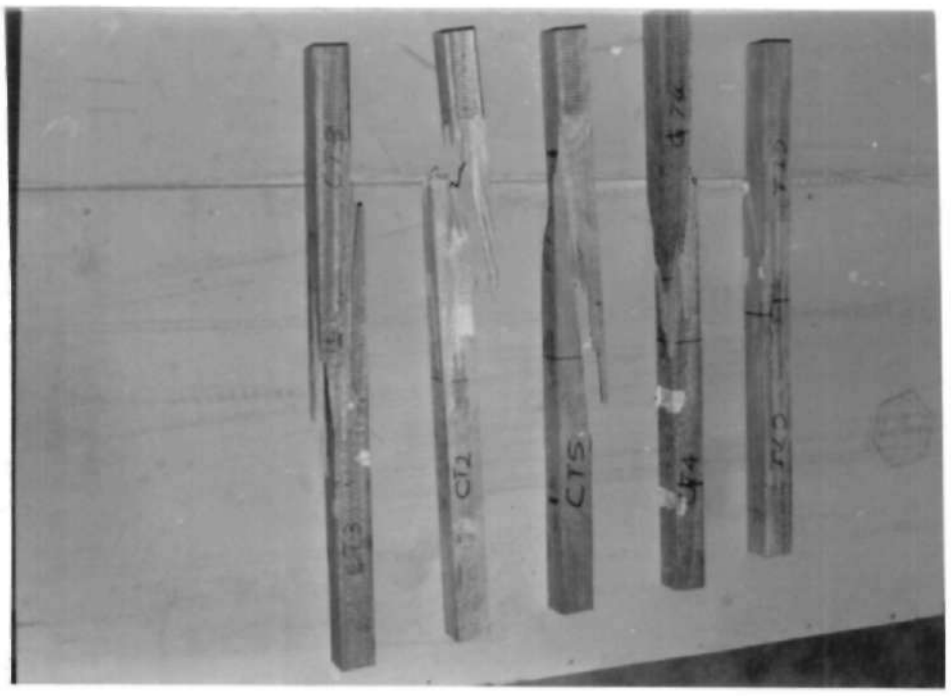


Plate 3.5: Tension Test Parallel to Grain, Broken Pieces after Test.

3.2.4 COMPRESSION TEST OF WOOD PARALLEL TO GRAIN

Object:

To study the action of wood under compressive loading parallel to the grain and to determine some of its physical and mechanical properties as follows:

(1) Moisture content

(2) Compressive stress at ultimate load

(3) Compressive stress at limit of proportionality

(4) modulus of elasticity

(5) Mode of failure

(6) Efficiency of glued joint pieces in respect to the clear pieces.

Specimen:

48 Nos of 475 x 85 x 35mm test pieces:- 5 Nos of 475 x 85 x 35mm clear wood, 5 Nos of 475 x 85 x 35mm finger joints (finger length = 55mm), 4 Nos of 475 x 85 x 35mm finger joint (length = 50mm), 3 Nos of 475 x 85 x 35mm finger joints (l = 40mm), 3 Nos of 475 x 85 x 35mm vertical component joints (slope 1:12), 4 Nos of 475 x 85 x 35mm vertical component joint pieces (slope 1:8), 7 Nos of 475 x 85 x 35mm plain scarf joint pieces - (slope 1:12), 4 Nos of 475 x 85 x 35mm) plain scarf joint pieces (slope 1:10), and 5 Nos of 475 x 85 x 35mm plain scarf joint pieces (slope 1:8).

Special Apparatus:

Universal compression testing Denison (Leeds, England) 50 ton machine, strainometers and 2 flat metal rectangular bars.

Procedure:

1. Make sure all the ends were planed at right

angles to the axis of the specimen. The cross section of each specimen was measured and recorded to the nearest 0.254mm.

2. A check was made to be sure that the machine was constructed such that plates between which the test pieces were to be placed are parallel to each other and remained so during the whole period of the test.

3. The strain-gauge cables fixed to the two opposite faces at the midspan of the test piece were connected to relevant channels on the strainometers and the universal testing machine and the strainometers were adjusted to zero reading.

4. The specimen was placed centrally between the plates of the testing machine (with the seated rectangular block) in order to ensure a uniform distribution of stresses and avoid eccentric loading.

5. The load was applied to the specimen in the direction of its length with the grains running parallel to the length of the wooden piece, through a rectangular seated metal flat block until failure. The increments were gradual and constant (1.5385kN/Sec. to 1.33KN/Sec). The strain readings were taken

from the strainometers corresponding to each load at intervals of 20kN.

6. The mode of failure was recorded and a moisture determination test block of 30 x 30 x 35mm was cut off near the failure. The sample was weighed immediately after removal and placed in a ventilated drying-oven controlled at 103 ± 2°C to a dried constant weight.

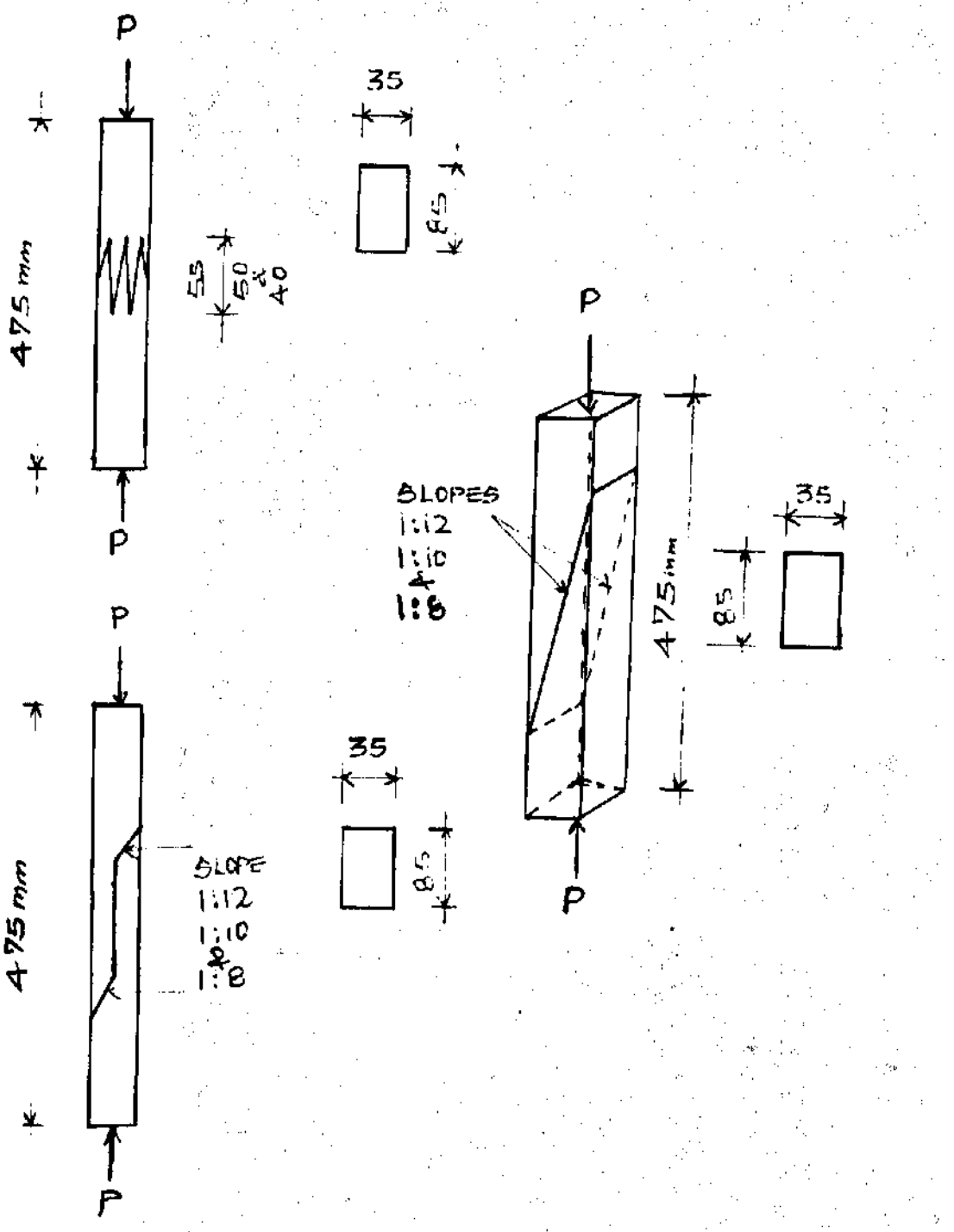
7. The form, dimensions and experimental arrangement for the compression test parallel to grain test pieces were as shown in Fig. 3.3 and Plates 3.6 and 3.7.

Report:

The recorded strains and the computed stresses were used to plot the stress-strain curve. The moisture content of each tested piece is calculated with compressive stress at ultimate load, compressive stress at limit of proportionality, modulus of elasticity, mode of failure and effeciency of glued joint pieces in respect to the clear pieces; as detailed under 3.2.4

Discussion:

The properties of wood obtained in this experiment and the other experiments are analysed and discussed in the next Chapter; Chapter Four.



ig. 3.3: Specimens of Compression Tests Parallel to Grain



Plate 3.6: Compression Test Parallel to Grain, Experimental Set-up



Plate 3.7: Modes of Failures Observed During Compression Parallel to Grain Laboratory Test.



Plate 3.8: Curing Glued Scarf Joint During the Experiment at Room Temp. with Rocker Head Clamps.

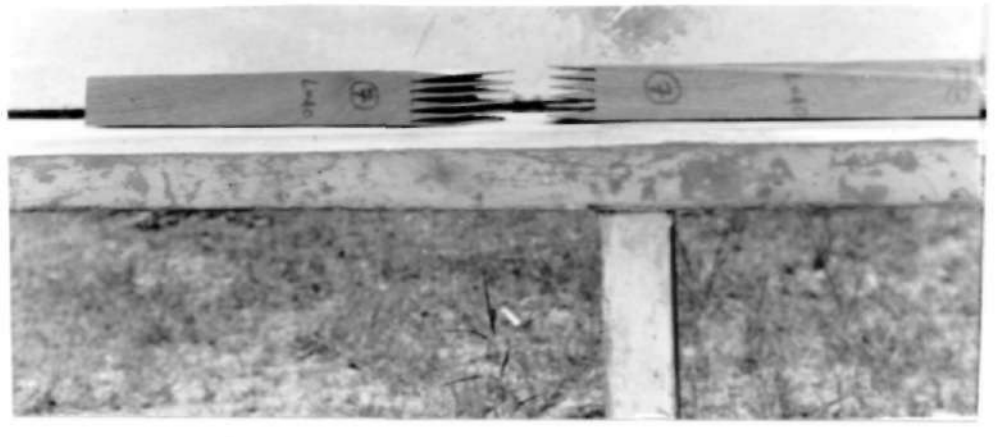


Plate 3.9: Fabricated (Cut) Finger Joint Pieces Ready for Gluing.

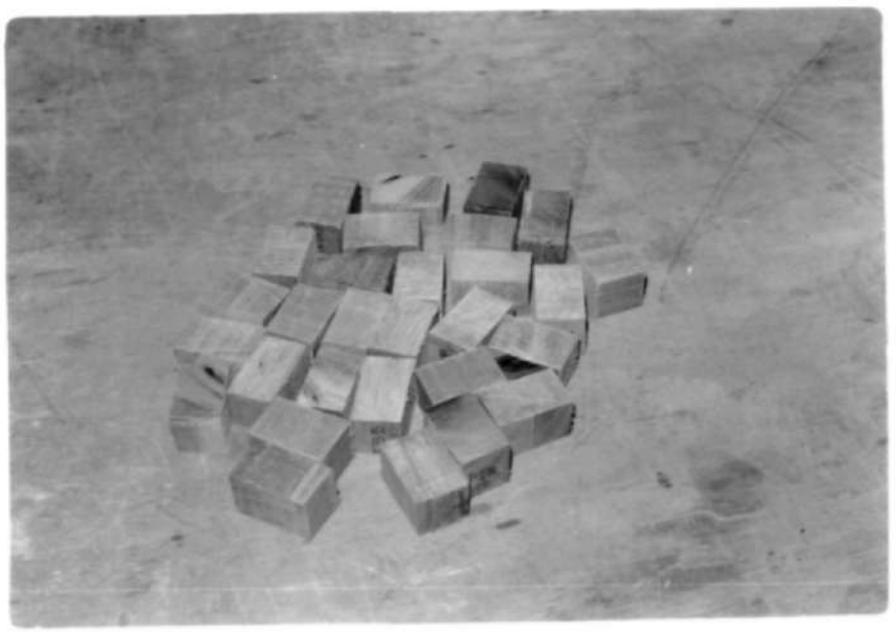


Plate 3.10: Moisture Content Determination Cubes (Oven Dried).

CHAPTER FOUR

4.0 ANALYSIS OF TESTS RESULTS AND DISCUSSION

4.1 RESULTS

The results of all the tests performed are summarized in Table 4.7 and 4.8.

Detailed results of mechanical properties of mahogany investigated in respect of static bending, compression parallel to grain and tension parallel to grain are found in Tables 4.1, 4.1.1, 4.2, 4.2.1, 4.3 and 4.3.1 respectively. The computed moisture content of each test piece is similarly found in Tables 4.4, 4.5 and 4.6 respectively.

4.2 ANALYSIS OF RESULTS

As discussed in the introductory and literature review chapters of this study, there are many factors that affect the strength properties of timber, the strength values obtained from the tests on the specimens vary not only between different batches, but also between pieces obtained from the same tree. We were told that timber is a very variable material and that for many of its parameters distinct patterns of variation could be established within a growth ring, outward from the pith[15] (pith is small, soft non woody core in the tree, about which the annual rings of growth are laid. It is normally near the goemetric centre of the trunk of the tree. Pith included in structural timber is dignated as boxed-heart timber, Wangaard, 1950 pp 149) towards the bark, upwards in the tree, as well as from tree to

tree. The effects of this variation in structure are all too apparent when mechanical tests are performed.

An efficient estimator of the variability which occurs in any one property is the sample standard deviation, denoted by S. It is the square root of the variance and is derived from the Formula[13]:

$$s = \sqrt{\left(\frac{\sum x^2 - (\sum x)^2/n}{n-1}\right)} = \frac{1}{n-1}\left(\sum_{1}^{n} X_i^2 - nx^2\right)$$

where

S = sample standard deviation

X = Every successive strength value (variate)

n = Number of strength (items) in the sample

The standard deviation, S, provides us with a measure of the variability, but in itself gives little impression of the magnitude unless related to the mean. This ratio is known as the coefficient of variation, CV.

The coefficient of variation, CV, gives the magnitude of the variability of the strength values (items) within a given sample. It is calculated as:

$$CV = \frac{S}{\text{mean}} \% = \frac{S}{\frac{\text{Sum }(x)}{n}}$$

where CV = Coefficient of variation

Sum (x)/n = mean or average value of a given sample

The coefficient of variation varies considerably but is frequently under 15% for many biological applications. However, this value is frequently exceeded. For design purposes the two most important properties are the muduli of elasticity and rupture.

4.3 FORMULAE AND PROPERTIES COMPUTATION

The formulae and parameter calculations of density, moisture content, fibre stress at limit of proportionality, modulus of rupture, modulus of elasticity, stresses at maximum load and Effeciences of joints for static Bending, compression parallel to grain and tension parallel to grain test specimens are found at APPENDIX 3.

4.4 REGRESSION ANALYSIS

Regression analyses[2] have been used widely in practically all branches of engineering for obtaining empirical relations between two (or more) variables. Sometimes the necessary relationship between two engineering variables can not be derived on the basis of theoretical considerations; in these cases the required relationship may be determined empirically on the basis of experimental observations.

If one or both variables are random, there will be no unique relationship between the values of the two variables, here a probabilistic description is required. If the probabilistic relationship between the variables is described in terms of the

mean and variance of one random variable as a function of the value of the other variable, we have what is known as regression analysis. When the analysis is limited to linear mean-value functions, it is called linear regression (line of best fit). In general, however, regression may be nonlinear. In some cases, non linear regression problems may be converted to linear ones by appropriate transformation of the original variables.

In this study, we have stress-strain curves for all the timber glued joints experimented on. It is observed that stress increases with increase in strain. In predicting one on the other let us say, stress and strain are variables. Let also, stress be dependent variate y, and strain be independent variate X.

Expressing these in a common regression form we shall have:

$$Y = A + B\,x \qquad (1)$$

where:

$$B = \frac{n\sum XY - \sum X \sum Y}{n\sum X^2 - (\sum X)^2} \qquad (2)$$

$$A = \frac{\sum Y - B\sum X}{n} \qquad (3)$$

r = coefficient of simple linear correlation (also referred to as pearsonian coefficient). It tells the degree of points

spread or variation normal to the line and the sign depend on the slope of the line.

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{[(n\sum X^2 - (\sum X)^2)(n\sum Y^2 - (\sum Y)^2]}} \qquad (4)$$

In relationships of variables plotted where the points are better described by smooth curves rather than by line of best fit, the data is best analysed under non-linear relationships like our stress-strain curves of figures A 1 - A. 19 of Appendix 2.

The non-linear regression analysis is usually based on nonlinear (mean value) function with certain undetermined coefficients that would be evaluated from experimental data.

The simplest type of non linear function for the regression of Y on X is

$$E(y/x) = \alpha + \beta\, g(x) \qquad (5)$$

where

g(x) = predetermined nonlinear function of x.

g(x) may be $x + x^2$, $e^x \mathrm{Ln}x$ or any other function of x.

α and β are constants

Better in polynomial relation:

$$E(y/x) = \alpha + \beta_1 x\, \beta_2 X^2 + \ldots\ldots + \beta_n X^n \qquad (6)$$

$$E(y/x) = \alpha + \beta_1 x\, Z_1 + \ldots\ldots + \beta_n Z^n \qquad (7)$$

where $Z_j = g_j(x)$

$g_j(x)$, $j = 1,2, \ldots\ldots\ldots$ m predetermined functions of the independent variable x.

Table 4.1: Results of Static Bending Test

Specimen Mark	Length (mm)	Depth (mm)	Breath (mm)	Weight (g)	Ultimate Load (N)	Load at LMT. of Prop. (L.P) (N)	Fibre stress at (L.P) (N/mm^2)	Modulus of Rupture (N/mm^2)	Modulus of Elasticity (N/mm^2)
FB2	758	145	49	4150	180,000	18,000	8.5	40.88	8,250.00
FB3	756	144	50	4199	180,000	22,000	4.0	40.63	4,444.44
FB3B	768	132	48	4150	65,000	26,000	8.5	19.59	4,250.00
FB4	753	146	48	3980	120,000	32,000	8.5	27.03	8,500.00
FB5	756	144	44	4080	120,000	36,000	7.75	30.78	8,333.33
FB6	757	143	50	4120	110,000	22,000	8.8	25.34	7,142.86
FB6B	759	137	47	3900	80,000	16,200	2.0	21.99	2,500.00
FB7	747	145	50	4090	80,000	26,000	1.0	17.39	1,000.00
FB8	744	133	49	3550	90,000	27,000	6.5	24.82	4,375.00
FB9	742	132	49	3770	80,000	26,000	1.5	22.39	1,666.67
SB1	690	130	47	3400	120,000	34,000	4.25	32.48	4,375.00
SB2	685	138	48	3670	180,000	36,000	7.0	40.27	7,500.00
SB3	700	130	46	3000	100,000	30,000	3.5	28.30	2,500.00
SB4	704	134	43	3300	110,000	28,000	1.4	31.06	2,000.00
SB5	697	131	47	3400	120,000	32,000	2.0	32.36	2,000.00
SB6	700	134	49	3500	120,000	26,000	3.5	29.46	4,545.45
SB7	700	132	47	3400	100,000	28,200	6.5	26.62	4,166.67
SB8	697	137	48	3680	120,000	28,000	5.0	28.17	6,666.67
SB9	702	138	48	3500	120,000	20,000	7.3	27.96	6,250.00
PI13	704	133	46	3400	40,000	16,000	5.4	10.77	3,125.00
PI14	703	132	42	33000	40,000	13,500	4.5	12.00	5,000.00
PI15	703	135	42	33000	60,000	27,000	1.25	16.97	2,500.00
CB1	702	142	48	3780	160,000	34,000	4.5	34.55	5,833.33
CB2	700	138	50	4050	170,000	36,000	7.7	37.85	8,333.33
CB3	701	139	48	3700	140,000	40,000	3.5	31.93	4,000.00
CB4	701	141	50	3800	180,000	26,000	7.0	37.94	7,857.14
CB5	703	139	49	3700	160,000	32,000	3.5	35.91	4,000.00

n = 27

Table 4.1.1: Summary of Static Bending Test Results

Specimen Mark	Fibre Stress at LMT of Prop. (L.P.) (N/mm^2)	Modulus of Rupture (N/mm^2)	Modulus of Elasticity (N/mm^2)	Density (Kg/m^3)	Moisture content (%)	Type of Joint	Mode of failure
FB2	8.5	40.88	8,250.00	770.57	12.73	Finger Joint length; L=55mm	Cross grain failure
FB3	4.0	40.63	4,444.44	771.42	12.50	Pitch; P = 12.5mm	Splintering in tension face
FB3B	8.5	19.59	4,250.00	852.85	13.79	tip; t = 1.5mm	Splintering in tension face
Mean; $\bar{X}$	7.0	33.70	5,648.15	798.28	13.01		
S.D.	2.6	12.22	2,255.37	47.26	0.69		
C.V.	0.37	0.36	0.40	0.06	0.05		
E.R.	133.6%	94.6%	94.1%	100.8%	93.4%		
FB4	8.5	27.03	8,500.00	754.21	19.23	Finger joint L = 50mm	Splintering in tension face
FB5	7.75	30.78	8,333.33	851.77	13.79	P = 12mm	Splintering in tension face
FB6	8.8	25.34	7,142.86	761.19	13.33	Tip Width;	Splintering in tension face
FB6B	2.0	21.99	2,500.00	798.00	15.38	t = 2mm	Fingers cut off from one piece
Mean; $\bar{X}$	6.76	26.29	6,619.05	791.29	15.43		
S.D.	3.21	3.66	2,811.74	44.66	2.68		
C.V.	0.47	0.14	0.42	0.056	0.17		
E.R.	129%	74%	110%	100%	111%		
FB7	1.0	17.39	1,000.00	755.20	16.07	Finger joint L = 40mm	Finger cut off into one piece
FB8	6.5	24.82	4,375.00	732.16	9.68	P = 9mm	Finger cut off into one piece
FB9	1.5	22.39	1,666.67	785.54	13.33	t = 1mm	Finger cut off into one piece
Mean; $\bar{X}$	3.0	21.53	2,347.22	757.63	13.03		
S.D.	3.04	3.79	1,787.46	26.77	3.21		
C.V.	1.01	0.18	0.76	0.035	0.25		
E.R.	57%	60%	39%	96%	94%		
SB1	4.25	32.48	4,375.00	806.47	16.36	Plain Scarf Joint	Cross grain failure.
SB2	7.0	40.27	7,500.00	808.83	13.79	Slope:	Horizontal shear.
SB3	3.5	28.30	2,500.00	716.67	11.54	1:12	Cross grain failure.
Mean; $\bar{X}$	4.92	33.68	4,791.67	777.32	13.90		
S.D.	1.84	6.08	2,525.91	52.54	2.41		

PlB13	5.4	10.77	3,125.00	789.40	12.90	Internal fibre shearing
PlB14	4.5	12.00	5,000.00	846.71	10.0	Internal fibre shearing
PB115	1.25	16.97	2,500.00	827.90	9.38	lap/(length, L = 150mm
Mean; $\bar{x}$	3.72	13.25	3,541.67	821.34	10.76	
S.D.	2.18	3.28	1,301.04	29.21	1.88	
C.V.	0.59	0.25	0.37	0.036	0.17	
E.R.	71%	37%	59%	104%	77%	
CB1	4.5	34.55	5,833.33	790.00	17.24	CLEAR SPECIMENS — Splintering at tension face
CB2	7.7	37.85	8,333.33	838.51	12.50	(CONTROLLED PIECE) — Horizontal shear.
CB3	3.5	31.93	4,000.00	791.09	13.85	(CONTROLLED PIECE) — Cross grain failure.
CB4	7.0	37.94	7,857.44	768.91	9.38	(CONTROLLED PIECE) — Horizontal shear failure
CB5	3.5	35.91	4,000.00	772.74	16.67	(CONTROLLED PIECE) — Horizontal shear.
Mean; $\bar{x}$	5.24	35.64	6,004.76	792.25	13.93	
S.D.	1.98	2.51	2,056.76	27.71	3.21	
C.V.	0.38	0.07	0.34	0.035	0.23	
E.R.	100%	100%	100%	100%	100%	

Table 4.1.1: cont'd

Specimen Mark	Fibre Stress at LMT of Prop. (L.P.) (N/mm²)	Modulus of Rupture (N/mm²)	Modulus of Elasticity (N/mm²)	Density (Kg/m³)	Moisture content (%)	Type of joint	Mode of failure
C.V.	0.37	0.18	0.53	0.068	0.17		
E.R.	94%	95%	80%	98%	100%		
SB4	1.4	31.06	2,000.00	813.52	8.33	**Plain Scarf joint**	Horizontal shear
SB5	2.0	32.36	2,000.00	792.28	10.77	**Slope: 1:10**	Cross grain/horizontal shear failure.
SB6	3.5	29.46	4,545.45	761.50	13.85		
Mean; $\bar{x}$	2.30	30.96	2,848.48	789.10	10.98		
S.D.	1.08	1.45	1,469.62	26.16	2.77		
C.V.	0.47	0.047	0.52	0.033	0.25		
E.R.	43.9%	87%	47.4%	100%	79%		
SB7	6.5	26.62	4,166.67	782.91	20.0	Scarf joint Slope; 1:8	Cross grain failure
SB8	5.0	28.17	6,666.67	802.88	12.50		Cross grain failure
SB9	7.3	27.96	6,250.00	752.68	13.79		Cross grain failure
Mean; $\bar{x}$	6.27	27.58	5,694.45	779.49	15.43		
S.D.	1.17	0.84	1,339.40	25.27	4.01		
C.V.	0.19	0.03	0.24	0.032	0.26		
E.R.	120%	77%	95%	98%	111%		

Table 4.1.1.1: Static Bending Test Pieces
Failure Patterns and Reasons of Failure (Explanations)

Specimen Mark	Type of Joint	Mode of Failure	Reasons of Failure
FB2	Finger glued joint: finger length, L=55mm finger pitch, P=12.5mm and finger tip, t=1.5mm	cross grain	Break up of bottom fibres near the support. The plane of maximum bending moment and maximum shear force.
FB3	same as above	Splintering in tension face	The point of failure is the point of maximum bending moment and the load exceeded the permissible tensile stress of the outer fibre
FB3B	same as above	same as above	same as above
FB4	Finger joint: L=50mm, P=12mm and t=2mm	same as above	zone of maximum bending moment and the tensile stress of the outer fibre was exceeded.
FB5	same as above	same as above	same as above
FB6	same as above	same as above	
FB6B	same as above	Fingers cut off from one piece in tension face (simple tension)	Point of max. B.M. and the load exceeded the tensile stress of the outer fibres
FB7	Finger glued joint: L=40mm, P=9mm and t=1.0mm	Fingers cut off from one piece centrally.	Point of max. B.M. and zero shear force. Tensile stresses at the outer fibres were exceeded
FB8	same as above	Simple tension failure	same as above
FB9	same as above	same as above	same as above
SB1	Plain Scarf glued joint Slope 1:12	cross grain	Plane of max. B.M. and max. Shear Force. Tensile Stresses at the outer fibres exceeded
SB2	same as above	Horizontal shear	Tear of fibres along the grain along a weak line parallel to neutral axis.
SB3	same as above	cross grain	Zone of max. B.M. and max. shear force. Tensile stresses at the outer face exceeded.
SB4	same as above	Horizontal shear	Tear of fibres along the grain along a line of weakness near the neutral axis.
SB5	same as above	cross grain/horizontal shear	Plane of max. B.M. and max. shear force and tear along weak fibres near the neutral axis
SB6	same as above	same as above	same as above
SB7	plain scarf glued joint slope 1:8	cross grain failure	plane of max. B.M. and shear force. Tensile stresses at the outer fibres exceeded.
SB8	same as above	same as above	same as above
SB9	same as above	same as above	same as above

Table 4.1.1.1 continued

Specimen Mark	Type of Joint	Mode of Failure	Reasons of Failure
PI13	partial integral glued joint lap joint, L=150mm	internal fibre shearing	internal fibre tearing along weak lines of tubular lamination to each other.
PI14	same as above	same as above	same as above
PI15	same as above	same as above	same as above
CB1	clear specimens (controlled pieces)	splintering at tension face	The point of max. bending moment. The permissible tensile stress of the outer face fibres were exceeded.
CB2	same as above	horizontal shear	Tear along line of weak fibres lamination.
CB3	same as above	cross grain	Point of max. B.M. and max. shear force leading to inclined tear at outer fibres.
CB4	same as above	horizontal shear failure	Tear along lines of weak fibrous lamination.
CB5	same as above	same as above	same as above.

Table 4.2: Compression Parallel to Grain Test Results: Mahogany (Khaya-Senegalensis) - Dry Zone

Specimen Mark	Length (mm)	Width/Depth (mm)	Breadth (mm)	Ultimate Load (N)	Weight (g)	Moisture Content (%)	Compressive Stress at Max. Load (N/mm^2)	Modulus of Elasticity (N/mm^2)
C1 - 55	474	83	39	157,000	1,250	7.63	48.50	13,000.00
C2 - 55	475	83	38	120,000	1,200	9.87	38.05	6,666.67
C3 - 55	474	84	37	140,000	1,200	8.56	45.05	14,000.00
C4 - 55	475	84	35	140,000	1,150	8.79	47.62	15,000.00
C5 - 55	471	85	35	140,000	1,150	7.92	47.06	8,000.00
C1 - 50	473	83	34	155,000	1,100	8.30	54.93	15,000.00
C2 - 50	475	82	33	155,000	1,020	9.45	57.28	13,333.33
C4 - 50	475	84	36	140,000	1,200	7.89	46.30	15,000.00
C5 - 50	472	83	35	135,000	1,050	14.54	46.47	11,666.67
C7 - 40	473	83	32	120,000	1,030	10.82	45.18	15,000.00
C9 - 40	474	85	35	180,000	1,250	8.06	60.50	20,000.00
C10 - 40	475	83	36	160,000	1,180	9.27	53.55	33,333.33
C1 - V.C.	474	84	33	123,000	1,020	15.00	44.37	27,000.00
C2 - V.C.	473	84	37	120,000	1,100	13.74	38.61	15,000.00
C5 - V.C.	474	83	36	145,000	1,100	11.16	48.53	10,000.00
C11 - V.C.	475	85	35	187,500	990	8.94	63.03	10,000.00
C13 - V.C.	474	82	35	115,000	1,100	8.30	40.07	5,000.00
C14 - V.C.	474	83	35	120,000	1,050	8.37	41.31	5,000.00
C15 - V.C.	474	83	35	120,000	1,100	8.42	41.31	8,333.33
C1 - S.F.	475	83	35	193,000	1,150	9.65	66.44	14,000.00
C2 - S.F.	475	83	35	158,000	1,120	9.65	54.39	3,750.00
C3 - S.F.	475	84	35	120,000	1,300	14.29	40.82	20,000.00
C4 - S.F.	475	83	36	153,000	1,120	10.00	51.20	22,500.00
C5 - S.F.	476	83	35	183,000	1,090	7.76	62.99	20,000.00
CF - S.F.	475	81	38	110,000	1,200	7.69	35.74	13,750.00
CG - S.F.	475	84	36	180,000	1,250	10.27	59.52	15,000.00
CA - S.F.	473	85	32	140,000	1,050	9.22	51.47	25,000.00
CB - S.F.	476	83	35	190,000	1,300	11.52	65.40	20,000.00
CD - S.F.	475	83	36	155,000	1,150	12.61	51.87	30,000.00
CE - S.F.	474	84	34	160,000	1,150	8.70	56.02	45,000.00
C1 - SC	475	83	33	160,000	1,240	9.93	58.42	14,286.00
C2 - SC	475	81	35	152,000	1,090	11.63	53.79	14,708.00
C3 - SC	475	83	33	180,000	1,050	7.98	65.72	22,000.00
C4 - SC	475	83	33	175,000	1,100	8.30	63.89	20,000.00
C5 - SC	474	84	36	170,000	1,320	8.70	56.22	18,333.33
CS1	474	83	36	200,000	1,200	8.70	66.93	16,666.67
CS2	475	83	34	180,000	1,100	10.44	63.78	20,000.00
CS3	474	83	33	142,000	1,050	8.70	51.84	20,000.00
CS4	470	84	35	177,500	1,120	12.24	60.37	20,000.00
CS6	475	84	35	177,500	1,100	12.50	60.37	16,666.67

n = 40

Table 4.2.1: Summary of Compression Parallel to Grain Test Results Specie: Mahogany (Khaya - Senegalensis); Dry - Zone

Specimen Mark	Cross Sectional Area (mm^2)	Ultimate Load (N)	Moisture Content (%)	Density (Kg/m^2)	Stress at L.P. N/mm^2	Compressive Stress at Max. Load (N/mm^2)	Modulus of Elasticity (N/mm^2)	Type of Joint	Mode of Failure
C1 - 55	3,237.0	157,000	7.63	814.68	6.5	48.50	13,000	FINGER JOINT	Shearing across grain at top fibres
C2 - 55	3,154.0	120,000	9.87	800.99	1.3	38.05	6,666.67	Length; L≈55mm	Shearing across grain at top fibres
C3 - 55	3,108.0	140,000	8.56	814.56	9.3	45.05	14,000	Pitch; P = 12.5mm	Shearing across grain at top fibres
C4 - 55	2,940.0	140,000	8.79	823.49	5.5	47.62	15,000	Tip Width;	Shearing Bottom
C5 - 55	2,975.0	140,000	7.92	820.71	3.3	47.06	8,000	t = 1.5mm	Shearing at acute angle
Mean; $\bar{x}$	3,082.8	139,400	8.55	814.89	5.18	45.27	11,333.33		
S.D	123.99	13,107.25	0.87	8.68	3.06	4.22	3,749.07		
C.V	0.04	0.094	0.10	0.011	0.59	0.093	3.33		
E.R	106.8%	75.5%	81.3%	100%	46.7%	74.6%	60.7%		
C1 - 50	2,822.0	155,000	8.30	824.09	14.1	54.93	15,000		
C2 - 50	2,706.0	155,000	9.45	793.56	6.2	57.28	13,333.33	FINGER JOINT	Shearing at Top near joint.
C4 - 50	3,024.0	140,000	7.89	835.42	5.6	46.30	15,000	L = 50 mm	Shearing at mid section
C5 - 50	2,905.0	135,000	14.54	765.77	5.7	46.47	11,666.67	P = 12 mm	Shearing at joint
Mean; $\bar{x}$	2,864.25	146,250	10.05	804.71	7.9	51.25	13,750	t = 2 mm	Bottom piece fingers cut off
S.D	134.17	10,307.76	3.07	31.41	4.14	5.69	1,595.71		
C.V	0.047	0.07	0.31	0.04	0.52	0.11	0.12		
E.R	99.3%	83.4%	95.5%	98.7%	71.2%	84.5%	73.7%		
C7 - 40	2,656.0	120,000	10.82	819.88	5.0	45.18	15,000		
C9 - 40	2,975.0	180,000	8.06	886.43	10.5	60.50	20,000	FINGER JOINT	Shearing across grain and splitting parallel to grain Wedge split
C10- 40	2,988.0	160,000	9.27	831.40	10.9	53.55	33,333.33	L ≈ 40 mm	Wedge split
Mean; $\bar{x}$	2,873.0	153,333.33	9.38	845.90	8.8	53.08	22,777.78	P ≈ 9 mm	Shearing across grain
S.D	188.04	30,550.50	1.38	35.57	3.3	7.67	9,477.07	t ≈ 1mm	
C.V	0.07	0.20	0.15	0.042	0.38	0.14	0.42		
E.R	99.6%	87.4%	89.2%	103.8%	79.3%	87.5%	122.0%		
C1 - VC	2,772.0	123,000	15.0	776.30	6.5	44.37	27,500	VERTICAL COMPONENT Slope 1:12	Splitting across grain at Top. Splitting at base
C2 - VC	3,108.0	120,000	13.74	748.26	5.0	38.61	15,000		
C5 - VC	2,988.0	145,000	11.16	776.67	5.5	48.53	10,000		
Mean; $\bar{x}$	2,956.0	129,333.33	13.3	767.08	5.67	43.84	17,500		
S.D	170.27	13,650.40	1.96	16.30	0.76	4.98	9,013.88		crushing

C.V	0.06	0.11	0.15	0.02	0.13	0.11	0.52
E.R %	102.4%	73.7%	126.4%	94.10%	51.1%	72.3%	93.7%

Table 4.2.1: Cont'd

Specimen Mark	Cross Sectional Area (mm^2)	Ultimate Load (N)	Moisture Content (%)	Density (Kg/m^2)	Stress at L.P. N/mm^2	Compressive Stress at Max. Load (N/mm^2)	Modulus of Elasticity (N/mm^2)	Type of Joint	Mode of Failure
C11 - VC	2,975.0	187,500	8.94	700.57	14.5	63.03	10,000	VERTICAL COMPONENT	Crushing and Shearing.
C13 - VC	2,870.0	115,000	8.30	808.60	2.5	40.07	5,000	Slope 1:8	Shearing at top.
C14 - VC	2,905.0	120,000	8.37	762.54	4.0	41.31	5,000		
C15 - VC	2,905.0	120,500	8.42	778.86	5.0	41.31	8,333.33	angle	Shearing at acute with horizontal at the top.
Mean; $\bar{X}$	2,913.75	135,625	8.51	767.64	6.5	46.43	7,083.33		
S.D	44.04	34,663.56	0.29	48.91	5.43	11.08	2,500		
C.V	0.015	0.26	0.034	0.064	0.84	0.24	0.35		
E.R	101%	77.3%	80.9%	94.2%	58.6%	76.5%	37.9%		
C1 - SF	2,905.0	193,000	9.65	833.41	9.5	66.44	14,000	PLAIN SCARF JOINT	Splitting to half Length
C2 - SF	2,905.0	158,000	9.65	811.67	9.0	54.39	3,750	Slope 1:12	Wedge Split.
C3 - SF	2,940.0	120,000	14.29	930.90	5.5	40.82	20,000		Wedge splitting
C4 - SF	2,988	153,000	10.00	789.12	6.3	51.20	22,500		Wedge shearing
C5 - SF	2,905	183,000	7.76	788.27	14.5	62.99	20,000		Shearing and splitting
CF - SF	3,078	110,000	7.63	920.77	6.5	35.74	13,750		same as above
CG - SF	3,024.0	180,000	10.27	870.23	12.2	59.52	15,000		Shearing and Splitting
Mean; $\bar{X}$	2,963.57	156,714.29	9.90	834.91	9.07	53.01	15,571.43		
S.D	68.54	31,873.26	2.20	50.79	3.33	11.36	6,232.83		
C.V	0.023	0.20	0.22	0.061	0.37	0.21	0.40		
E.R	102.7%	89.3%	94.1%	102.4%	81.7%	87.4%	83.4%		
CA - SF	2,720.0	140,000	9.22	816.13	6.5	51.47	25,000	PLAIN SCARF JOINT, SLOPE 1:10	Crushing wedge split at top fibres
CB - SF	2,905.0	190,000	11.52	940.14	8.5	65.40	20,000		Wedge split at Bottom.
CD - SF	2,988.0	155,000	12.61	810.26	5.5	51.87	30,000		Shearing and splitting along the joint.
CE - SF	2,856.0	160,000	8.70	849.50	6.5	56.02	45,000		
Mean; $\bar{X}$	2,867.25	161,250	10.51	854.01	6.75	56.19	30,000		
S.D	112.27	20,966.24	1.86	59.97	1.26	6.48	10,801.23		
C.V	0.040	0.13	0.18	0.07	0.19	0.12	0.36		

E.R	99.4%	91.9%	99.9%	104.8%	60.8%	92.6%	160.7%	

Table 4.2.1: Cont'd

Specimen Mark	Cross Sectional Area (mm^2)	Ultimate Load (N)	Moisture Content (%)	Density (Kg/m^3)	Stress at L.P. N/mm^2	Compressive Stress at Max. Load (N/mm^2)	Modulus of Elasticity (N/mm^2)	Type of Joint	Mode of Failure
C1 - SC	2,739.0	160,000	9.93	953.09	12.5	58.42	14,286	PLAIN SCARF JOINT, SLOPE 1:8	Shearing at bottom
C2 - SC	2,835.0	152,500	11.63	809.43	14.0	53.79	14,708		Shearing at top.
C3 - SC	2,739.0	180,000	7.98	807.06	13.0	65.72	22,000		Shearing and splitting at bottom.
C4 - SC	2,739.0	175,000	8.30	845.49	12.0	63.89	20,000		Shearing at acute angle to fibres.
C5 - SC	3,024.0	170,000	8.70	920.90	13.0	65.62	18,333.33		Shearing at acute angle.
Mean; $\bar{X}$	2,815.2	167,500	9.31	867.19	12.9	59.61	17,865.47		
S.D	123.90	11,180.34	1.49	66.49	0.74	5.06	3,341.10		
C.V	0.044	0.067	0.16	0.077	0.06	0.085	0.19		
E.R	97.6%	95.5%	88.5%	106.4%	116.2%	98.3%	95.7%		
CS1	2,988.0	200,000	8.70	847.27	13.5	66.93	16,666.67	CLEAR SPECIMEN	Shearing off.
CS2	2,822.0	180,000	10.44	820.62	10.5	63.78	20,000		Wedge split.
CS3	2,739.0	142,000	8.70	808.75	10.5	51.84	20,000	CLEAR SPECIMEN	Splitting.
CS4	2,940.0	177,500	12.24	810.54	8.0	60.37	20,000	CLER SPECIMEN	Shearing at top of piece.
CS6	2,940.0	177,500	12.50	787.68	13.0	60.37	16,666.67	CLEAR SPECIMEN	Splitting/shearing.
Mean; $\bar{X}$	2,885.8	175,400	10.52	814.97	11.1	60.66	18,666.67		
S.D	102.4	20,920.68	1.84	21.67	2.22	5.63	1,825.74		
C.V	0.035	0.12	0.17	0.027	0.20	0.09	0.10		
E.R	100%	100%	100%	100%	100%	100%	100%		

Table 4.2.1.1: Types of failure in wood under compression parallel to the grain and reasons of failure in Mahogany, Dry-zone.

Specimen Mark	Type of Joint	Mode of Failure	Reasons of Failure
C1-55	Finger glued joint Finger length, L=55mm Pitch, P=12.5mm and Tip width, t=1.5mm	shearing across grain at top fibres	Eccentrically loaded.
C2-55	same as above	shearing at top fibres	*Eccentrical loading*
C3-55	same as above	same as above	same as above
C4-55	same as above	shearing at bottom fibres	Collapse of fibres because of non-parallel nature of grains. Inclined.
C5-55	same as above	shearing at acute angle	The piece has different strength zones along the length.
C1-50	Finger glued joint. L=50mm, P=12mm, t=2mm	shearing at top unit near joint	Testpiece have varying strength zones along its length.
C2-50	same as above	shearing at midsection	Joint lead failure
C4-50	same as above	shearing at joint	Joint failure
C5-50	same as above	Bottom piece fingers cut off.	same as above
C7-40	Finger glued joint. L=40mm, P=9mm, t=1.0mm	shearing across grain	Collapse of fibres as a column
C9-40	same as above	Splitting parallel to grain/wedge split	Collapse due to varying strength zones within the piece.
C10-40	same as above	shearing across grain at acute angle	*Varying strength blocks within the piece.*
C1-VC	Vertical component glued joint. slope 1:12	Splitting across grain at the top	Prior splitting weak line by growth.
C2-VC	same as above	Splitting at the base	Tear of fibres along weak line
C5-VC	same as above	Crushing	Grains not parallel and the vertical load caused collapse of fibres.
C11-VC	Vertical component glued joint. Slope 1:8	Crushing and shearing	Non-parallel of grains and different strength zone along the length of the piece.
C13-VC	same as above	shearing at top	Eccentrical loading
C14-VC	same as above	shearing at acute angle *with the horizontal at the top.*	same as above
C15-VC	same as above	same as above	same as above

Table 4.2.1.1 continued

Specimen Mark	Type of Joint	Mode of Failure	Reasons of Failure
C1-SF	Plain Scarf glued joint Slope 1:12	Splitting to half length	Prior splitting weak line by growth.
C2-SF	same as above	Wedge Split	Varying strength zones within the length of the piece due to nonhomogenuity of molecular and fibre growth (different colours).
C3-SF	same as above	same as above	same as above
C4-SF	same as above	same as above	same as above
C5-SF	same as above	shearing and splitting	Presence of different strength zones within the length of the piece.
CF-SF	same as above	same as above	same as above
CG-SF	same as above	same as above	
CA-SF	Plain Scarf glued joint. Slope 1:10	Crushing	Grains not parallel and vertical load caused collapse of fibres.
CB-SF	same as above	Wedge split at top fibres	Upper portion is stronger than the lower portion. Different strength zones.
CD-SF	same as above	Wedge split at bottom	Varying strength zones of top and bottom portions of the piece.
CE-SF	same as above	shearing and splitting along the joint	Joint failure
C1-SC	plain scarf glued joint.	Shearing at bottom	Grains not parallel with the piece frame thereby creating weak zones
C2-SC	same as above	shearing at top	Eccentrically loading.
C3-SC	same as above	shearing and splitting at bottom	Varying strength zones within the piece and lines of fibre breakage during growth.
C4-SC	same as above	shearing at acute angle at top fibres	Eccentric loads.
C5-SC	same as above	shearing at acute angle.	Varying strength zones shown by coloration of grains.
CS1	Clear specimen (control piece)	Shearing off (cut)	Existence of two different zones of strength in the piece.
CS2	same as above	Wedge split	Top part stronger than the central and lower portions.
CS3	same as above	Splitting	Grains not parallel. Tear through of fibre laminations. Line of weakening during growth.
CS4	same as above	Shearing at the top of piece	Eccentric loading.
CS6	same as above	Splitting and shearing	Varying strength zones within the piece and line of fibre weakening during growth.

Table 4.3: Tension Parallel to Grain Test Results. Specie: Mahogany (Khaya-Senegalensis); Dry-Zone

Specimen Mark	Length (mm)	Width Depth (mm)	Breath (mm)	Ultimate Load (N)	Weight (g)	Moisture Content (%)	Tensile Stress at L.P. (N/mm^2)	Tensile Stress at Max. Load (N/mm^2)	Modulus of Elasticity (N/mm^2)
SSLT1	462	30	30	13,000	520	8.18	0.78	14.44	3,333.33
SSLT2	464	30	30	14,000	520	8.89	0.58 $\bar{x}$ =	15.56	1,666.67
SSLT3	464	30	30	14,500	520	8.57	2.20 1.34	16.11	55,000
SSLT4	461	30	30	14,500	560	9.30	1.80	16.11	36,000
CT1	449	30	30	39,000	330	6.98	8.75	43.33	15,000
CT2	448	30	30	44,500	320	11.11	2.50 $\bar{x}$ =	49.44	4,000
CT3	450	30	30	38,000	380	7.32	9.00 7.50	42.22	18,000
CT4	450	30	30	35,000	330	8.10	9.75	38.89	22,500

Table 4.3.1: Summary of Tensile Parallel to Grain Test Results. Specie: Mahogany (Khaya-Senegalensis); Dry-Zone

Specimen Mark	Cross Sectional Area (mm^2)	Ultimate Load (N)	Moisture Content (%)	Density (Kg/m^3)	Ultimate Tensile Stress (N/mm^2)	Modulus of Elasticity (N/mm^2)	Type of Joint	Mode of Failure
SSLT 1	900	13,000	8.18	825.40	14.14	3,333.33	SINGLE SHEAR LAP JOINT	Shearing failure along the joints.
SSLT 2	900	14,000	8.89	824.22	15.56	1,666.67		Shearing failure along the joints.
SSLT 3	900	14,500	8.57	824.22	16.11	55,000	(238mm lapped)	Shearing failure along the joints.
SSLT 4	900	14,500	9.30	891.44	16.11	36,000	(237mm lapped)	Shearing failure along the joints.
Mean; $\bar{x}$	900	14,000	8.74	841.32	15.48	24,000	(237mm lapped)	Shearing failure along the joints.
S.D.	0	707.11	0.48	33.42	0.93	26,018.51	(237mm lapped)	
C.V.	0	0.051	0.055	0.04	0.06	1.084		
E.R.	100%	35.8%	104.3%	100.1%	35.6%	161.34%		
CT1	900	39,000	6.98	816.63	43.33	15,000	CLEAR SPECIMEN	Ruptured within the length of specimens.
CT2	900	44,500	11.11	793.65	49.44	4,000	CLEAR SPECIMEN	Ruptured within the length of specimens.
CT3	900	38,000	7.32	938.27	42.22	18,000	CLEAR SPECIMEN	Rupture within the length of specimens.
CT4	900	35,000	8.10	814.81	38.89	22,500	CLEAR SPECIMEN	Ruptured within the length of specimens.
Mean; $\bar{x}$	900	39,125	8.38	840.84	43.47	14,875		
S.D.	0	3,966	1.88	65.79	4.40	7,877.98		
C.V.	0	0.10	0.22	0.073	0.10	0.53		
E.R.	100%	100%	100%	100%	100%	100%		

Table 4.3.1.1 *Types of Failure in Mahogany under Tension Test parallel to grain and reasons of failures.*

Specimen Mark	Type of Joint	Mode of Failure	Reasons of Failure
SSLT1	Single Shear Lap Glued Joint. Lap=237mm	Shearing along joint	failure in glue line
SSLT2	same as above	same as above	same as above
SSLT3	same as above	same as above	same as above
SSLT4	same as above	same as above	same as above
CT1	Clear specimen (controlled piece)	Ruptured within the length of the specimen.	The exerted direct tensile stress exceeded the allowable stresses in the fibres of the piece.
CT2	same as above	same as above	same as above
CT3	same as above	same as above	same as above
CT4	same as above	same as above	same as above

Table 4.4: Moisture Content Determination of Bending Test Results. Specie: Mahogany (Khaya-Senegalensis); Dry-Zone

Specimen Mark	Section L x B x H	Initial Weight at Room Temp.	Oven-dry Final Weight at 103 ± 2°C	Moisture Content
	(mm x mm x mm)	(g)	(g)	(%)
FB2	49 x 30 x 30	31.0	27.5	12.73
FB3	50 x 30 x 30	36.0	32.0	12.5
FB3B	47.5 x 30 x 30	33.0	29.0	13.79
FB4	50 x 30 x 30	31.0	26.0	19.23
FB5	50 x 30 x 30	33.0	29.0	13.79
FB6	45 x 30 x 30	34.0	30.0	13.33
FB6B	50 x 30 x 30	30.0	26.0	15.38
FB7	49 x 30 x 30	32.5	28.0	16.07
FB8	49 x 30 x 30	34.0	31.0	9.68
FB9	49 x 30 x 30	34.0	30.0	13.33
SB1	48 x 28 x 30	32.0	27.5	16.36
SB2	48 x 30 x 30	33.0	29.0	13.79
SB3	45 x 30 x 30	29.0	26.0	11.54
SB4	48 x 30 x 30	32.5	30.0	8.33
SB5	47 x 30 x 30	36.0	32.5	10.77
SB6	49 x 30 x 30	37.0	32.5	13.85
SB7	46 x 30 x 30	33.0	27.5	20.0
SB8	49 x 30 x 30	36.0	32.0	12.5
SB9	50 x 30 x 30	33.0	29.0	13.79
PIB13	46 x 30 x 30	35.0	31.0	12.9
PIB14	45 x 30 x 30	33.0	30.0	10.0
PIB15	47 x 30 x 30	35.0	32.0	9.38
CB1	49 x 30 x 30	34.0	29.0	17.24
CB2	48 x 30 x 30	36.0	32.0	12.5
CB3	48 x 30 x 30	37.0	32.5	13.85
CB4	50 x 30 x 30	35.0	32.0	9.38
CB5	48 x 30 x 32	35.0	30.0	16.67

Mean, $\bar{X}$ = 13.43%
S.D. (σn) = 2.86
C.V. = 0.21
n = 27

Table 4.5: Moisture Content Determination of Compression Parallel to Grain Test Results. Specie of Test Pieces: Mahogany (Khaya-Senegalensis); Dry-Zone

Specimen Mark	Section L x B x H	Initial Weight at Room Temp.	Oven-dry Final Weight at 103 ± 2°C	Moisture Content
	(mm x mm x mm)	(g)	(g)	(%)
C1 - 55	39 x 30 x 30	26.8	24.9	7.63
C2 - 55	36 x 30 x 30	24.5	22.3	9.87
C3 - 55	34 x 30 x 30	24.1	22.2	8.56
C4 - 55	35 x 30 x 30	26.0	23.9	8.79
C5 - 55	36 x 30 x 30	25.9	24.0	7.92
C1 - 50	34 x 30 x 30	24.8	22.9	8.30
C2 - 50	32 x 30 x 30	22.0	20.1	9.45
C4 - 50	37 x 30 x 30	24.6	22.8	7.89
C5 - 50	36 x 30 x 30	26.0	22.7	14.54
C7 - 40	32 x 30 x 30	25.6	23.1	10.82
C9 - 40	36 x 30 x 30	26.8	24.8	8.06
C10- 40	37 x 30 x 30	27.1	24.8	9.27
C1 - VC	34 x 30 x 30	23.0	20.0	15.0
C2 - VC	36 x 30 x 30	24.0	21.1	13.74
C5 - VC	36 x 30 x 30	24.9	22.4	11.16
C11- VC	34 x 30 x 30	19.5	17.9	8.94
C13- VC	34 x 30 x 30	24.8	22.9	8.30
C14- VC	35 x 30 x 30	22.0	20.3	8.37
C15- VC	34 x 30 x 30	22.0	20.2	8.42
C1 - SF	35 x 30 x 30	25.0	22.8	9.65

Table 4.5 Cont'd

Specimen Mark	Section L x B x H	Initial Weight at Room Temp.	Oven-dry Final Weight at 103 ± 2°C	Moisture Content
	(mm x mm x mm)	(g)	(g)	(%)
C2 - SF	35 x 30 x 30	25.0	22.8	9.65
C3 - SF	35 x 30 x 30	32.0	28.0	14.29
C4 - SF	37 x 30 x 30	27.5	25.0	10.0
C5 - SF	35 x 30 x 30	25.0	23.2	7.76
CF - SF	35 x 30 x 30	28.0	26.0	7.69

CG - SF	38 x 30 x 30	29.0	26.3	10.27
CA - SF	32 x 30 x 30	22.5	20.6	9.22
CB - SF	35 x 30 x 30	30.0	26.9	11.52
CD - SF	36 x 30 x 30	25.0	22.5	12.61
CE - SF	35 x 30 x 30	25.0	23.0	8.70
C1 - SC	32 x 30 x 30	31.0	28.2	9.93
C2 - SC	33 x 30 x 30	24.0	21.5	11.63
C3 - SC	33 x 30 x 30	23.0	21.3	7.98
C4 - CF	33 x 30 x 30	26.0	24.0	8.30
C5 - SC	37 x 30 x 30	27.5	25.3	8.70
CS1	38 x 30 x 30	27.5	25.3	8.70
CS2	35 x 30 x 30	27.5	24.9	10.44
CS3	35 x 30 x 30	25.0	23.0	8.70
CS4	36 x 30 x 30	27.5	24.5	12.24
CS6	30 x 30 x 30	22.5	20.0	12.50

Mean, $\overline{X}$ = 9.89%, S.D. = 2.01, C.V. = 0.20, n = 40

Table 4.6: Results of Moisture Content Determination. Tension Parallel to Grain Test Pieces. Specie: Mahogany (Khaya-Senegalensis)

Specimen Mark	Section L x B x H	Initial Weight at Room Temp.	Oven-dry Final Weight at 102 ± 3°C	Moisture Content
	(mm x mm x mm)	(g)	(g)	(%)
SSLT 1	30 x 30 x 30	23.8	22.0	8.18
SSLT 2	34 x 30 x 30	24.5	**22.5**	**8.89**
SSLT 3	30 x 30 x 30	22.8	**21.0**	**8.57**
SSLT 4	32 x 30 x 30	23.5	**21.5**	**9.30**
CT1	32 x 29 x 29	23.0	**21.5**	**6.98**
CT2	30 x 29 x 30	18.0	**16.2**	11.11
CT3	30 x 30 x 30	22.0	**20.5**	**7.32**
CT4	32 x 29 x 30	22.7	**21.0**	**8.10**

Mean, $\overline{X}$	=	8.56%
S.D.	=	1.28
C.V.	=	0.15
n	=	8

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TABLE 4.7 . OVER ALL SUMMARY OF TESTS RESULTS (CONSTRUCTIONAL WOOD SIZES' STRENGTH VALUES)

SPECIES: MAHOGANY (KHAYA-SENEGALENSIS); DRY-ZONE

TYPE AND PROFILES OF TIMBER GLUED JOINTS	STATIC BENDING					COMPRESSION PARALLEL TO GRAIN					TENSION PARALLEL TO GRAIN				
	DENSITY	MOISTURE CONTENT AT TEST	FIBRE STRESS AT LMT. OF PROP.(L P).	MODULUS OF RUPTURE	MODULUS OF ELASTICITY	DENSITY	MOISTURE CONTENT AT TEST	STRESS AT LMT OF PROP(L'P)	STRESS AT MAX. LOAD ULT. L'D(L'D)	MODULUS OF ELASTICITY	DENSITY	MOISTURE CONTENT AT TEST	STRESS LMT OF PROP (L'P)	STRESS AT MAX LOAD	MODULUS OF ELASTICITY
FINGER GLUED JOINTS:	kg/m3	%	N/mm^2	N/mm^2	N/mm^2	kg/m^3	%	N/mm^2	N/mm^2	N/mm^2	kg/m^3	%	N/mm^2	N/mm^2	N/mm^2
Length;L=55,Pitch=12.5mm& Tip=,t=1.5	798.28	13.01	7.0	33.70	5,648.15	814.89	8.55	5.18	45.27	11,333.33					
L=50mm;P=12mm;&t=2.0mm	791.29	15.43	6.76	26.29	6,619.05	804.71	10.05	7.9	51.25	13,750					
L=40mm,P=9mm&t=1.0mm	757.63	13.03	3.0	21.53	2,347.22	845.90	9.38	8.8	53.08	22,777.78					
PLAIN SCARF GLUED JOINTS:															
Slope 1:12 (4.76°)	777.32	13.90	4.92	33.68	4,791.67	834.91	9.90	9.07	53.01	15,571.43					
" 1:10 (5.71°)	789.10	10.98	2.30	30.96	2,848.48	854.01	10.51	6.75	56.19	30,000					
1:8 (7.13°)	779.49	15.43	6.27	27.58	5,694.45	867.19	9.31	12.9	59.61	17,865.47					
PARTIAL INTEGRAL GLUED JOINTS	821.34	10.76	3.72	13.25	3,541.67	-	-	-	-	-					
VERTICAL COMPONENT GLUED JOINTS:															
SLOPE 1:12	-	-	-	-	-	767.08	13.3	5.67	43.84	17,500					
1:8	-	-	-	-	-	767.64	8.51	6.5	46.43	7,083.33					
SINGLE SHEAR LAP GLUED JOINTS.	-	-	-	-	-	-	-	-	-	-	841.32	8.74	1.34	15.48	24,000
CLEAR SPECIMENS (CONTROLLED PIECES)	792.25	13.93	5.24	35.64	6,004.76	814.97	10.52	11.1	60.66	18,666.66	840.84	8.34	7.50	43.47	14,875

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TABLE 4.8 EFFICIENCY RATINGS OF SELECTED TIMBER GLUED JOINTS' PROFILES

SPECIES: MAHOGANY (KHAYA-SENEGALENSIS); DRY - ZONE

TYPE AND PROFILES OF TIMBER GLUED JOINTS	STATIC BENDING					COMPRESSION PARALLEL TO GRAIN					TENSION PARALLEL TO GRAIN				
	DENSITY	MOISTURE CONTENT AT TEST	FIBRE STRESS AT LMT. OF PROP(L.P)	MODULUS OF RUPTURE	MODULUS OF ELASTICITY	DENSITY	MOISTURE CONTENT AT TEST	STRESS AT LMT OF PROP(L.P)	STRESS AT MAX LOAD (U.L)	MODULUS OF ELASTICITY	DENSITY	MOISTURE CONTENT AT TEST	STRESS AT LMT OF PROP	STRESS MAX. LOAD	MODULUS OF ELASTICIT
FINGER JOINT PROFILE	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Length;L=55mm,Pitch;P=12.5mm&Tipwt=1.5	100.8	93.4	133.6	94.6	94.1	99.99	81.3	46.7	74.6	60.7					
L=50mm, P=12mm & Tipwt; t=2.0mm	100	111	129	73.8	110	98.7	95.5	71.2	84.5	73.7					
L=40mm,P=9mm & t=1.0mm	96	94	57	60.4	39	103.8	89.2	79.3	87.5	122.0					
PLAIN SCARF JOINTS:															
SLOPE 1:12 (4.76°)	98	100	94	94.5	80	102.4	94.1	81.7	87.4	83.4					
1:10 (5.71°)	100	79	43.9	86.9	47.4	104.8	99.9	60.8	92.6	160.7					
1:8 (7.13°)	98	111	120	77.4	95	106.4	88.5	116.2	98.3	95.7					
PARTIAL INTEGRAL JOINT															
LAP LENGTH; L=150mm	104	77	71	37.2	59										
VERTICAL COMPONENT JOINTS:															
1:12 (4.76°)	-	-	-	-	-	94.1	126.4	51.1	72.3	93.7					
1:8 (7.13°)	-	-	-	-	-	94.2	80.9	58.6	76.5	37.9					
SINGLE SHEAR LAP JOINT:															
LAP LENGTH; Lp = 237mm&Lfull=350	-	-	-	-	-	-	-	-	-	-	100.1	104.3	17.9	[illegible]	161.3
CLEAR SPECIMENS (CONTROLLED SAMPLES)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

4.5 DISCUSSION OF TEST RESULTS

As can be observed from the Tables, many mechanical properties peculiar to the three tests carried out were considered to arrive at a correct efficiency rating of test pieces and joints fabricated. It can also be observed that only two out of seventy-five test pieces had moisture content slightly above 18.0%. We can therefore, say that all the test pieces were tested in 'dry' condition.

From the analysis of the results we shall discuss the behaviour of each glued joint type and its efficiency (mechanical and physical properties) as was observed and computed per the three tests.

4.5.1 STATIC BENDING (FLEXURAL) TEST

The static Bending strength of wood is its cross breaking strength or its strength as a beam. The static bending tests measure the effect of compressive, tensile and shear stresses operating together. The influence of shear stresses is however eliminated by applying the load at two points, equidistant from the points of supports.

The first and most important strength properties of static bending test of wood is the modulus of rupture or the fibre stress at maximum load. The other valuable properties are shear stress, density, moisture content, flexibility, stiffness and modulus of elasticity which affect the strength of wood at varying exposure conditions.

The stress-strain curves of static bending test Fig. B.1 to B.8 show that strain increases with increase in stress and the curves depict the first portion of the standard normal distribution.

The results of Table 4.1, 4.1.1, 4.4, 4.7 and 4.8 reveal that out of the five (5) different types and ten (10) profiles of mahogany glued joints considered for static bending test and comparing their results, with the result of the controlled specimens (36.64N/mm^2; 100%), the efficiencies of the various joints to resist stress or the stress that the fibres of the joint specimens are able to exert before failure is stated below, from the highest (best) joint producing bending resisting stresses to the least joint producing the least bending resisting stress:

FINGER GLUED JOINT WITH 55mm length, Pitch 12.5mm and Tip width 1.5mm (33.70N/mm^2; 94.6%) > PLAIN SCARF GLUED JOINT WITH SLOPE 1:10; 5.71° (33.68N/mm^2; 94.5%) > PLAIN SCARF GLUED JOINT WITH SLOPE 1:8; 7.13° (30.96N/mm^2; 86.9%) > FINGER GLUED JOINT WITH L = 50mm, P = 12mm, and t = 2.0mm (26.29N/mm^2; 73.8%) > FINGER GLUED JOINT WITH L = 40mm, P = 9mm and t = 1.0mm (21.53N/mm^2; 60.4%) > PARTIAL INTEGRAL LAP, LAPPED 150mm LONG (13.25N/mm^2; 37.2%).

In terms of the modulus of elasticity, which is a measure of the relation between stress and strain within the limit of proportionality, all the glued specimens are found to be more flexible than the unjointed (controlled) test pieces except

finger glued joint with length 50mm, pitch 12mm and Tip width 2.0mm, which we shall say is stiffer than the controlled pieces.

This is because the greater the modulus of elasticity the stiffer the timber, and, conversely, the lower the modulus of elasticity the more flexible it is. The controlled specimen has a mean of 6,004.76N/mm^2 as the modulus of elasticity compared with the modulus of elasticity (mean value) of mahogany (Dry zone) of 9,500N/mm^2 in Table 9 of NCP2: 1973.

The highest density was recorded for the partial integral glued joint as 821.34Kg/m^3 and the lowest for finger glued joint of finger length 40mm, pitch 9mm and tip width 1.0mm as 757.63Kg/m^3. The strength group of N3, mahogany (Dry-zone, Khaya Senegalensis) has a density at 18% moisture content of 816Kg/m^3 which is quite close comparatively.

The mean moisture content of twenty-seven (27) number of static bending pieces is 13.43% which is "Air dry" and suitable for all the various purposes of timber construction (≤ 18%) in the Northern Zone of Nigeria.

In the static bending test, failure of test pieces exhibited the common seven (7) modes of failure of wooden beams sketched in Fig. 1.6(a) to (f) and as recorded in Table 4.1.1 for each specimen. The commonest failure pattern noticed was splintering in tension face which were followed by cross grain and horizontal shear failures. There are different types of failures, because timber is a low density, cellular, polymeric composite (fibre composite), thus its non-homogenuity in density, colour and

moisture returning capacity (cell lengths and micro fibrillar angle of S_2 layer within a growth ring), variation in porosity and the presence of spiral cross-grains produced naturally in the living tree. The above reasons accounts for variability in strength of timber. Other reasons are the duration of the load and the possibility of accidental over load. Also important is the gluability factors: The type of wood, the way the wood is cut and used (instruments and skills). The surface quality of the wood specimens (control and jointed pieces). The adhesive. The bending process. The type of joint. The service environment. The angle of the load to the direction of the grains and the glue line[13] (Illston etal, 1979). Further explanation of failure mode type of each bending test piece is given in Table 4.1.1.1.

4.5.2 COMPRESSION PARALLEL TO GRAIN TEST

The maximum strength of timber parallel to the grain is obtained by dividing the maximum load recorded during the test by the cross-sectional area of the specimen. This property is the most important in the uniaxial compression mode of loading. Other properties of this test are modulus of Elasticity (E) and compressive stress at limit of proportionality (C.S. at L.P).

From the results of Tables 4.2, 4.2.1, 4.5, 4.7 and 4.8 and stress-strain curves Fig. C.1 to C.9 show that out of the eight types of mahogany glued joints experimented upon for compressive test all the joint behave like clear mahogany piece. Below is the grading of the efficiencies of mahogany glued joints experimented

upon for compressive test. The joints are arranged from the one with the highest compressive strength 59.61N/mm^2 and efficiency of 98.3% comparable to the control specimen of compressive strength 60.60N/mm^2 with 100% efficiency to the least joint with 43.84N/mm^2 compressive strength with 72.3% efficiency comparative to the control specimen of 60.60N/mm^2.

PLAIN SCARF GLUED JOINT WITH SLOPE 1:8 (7.13°) > PLAIN SCARF GLUED JOINT WITH SLOPE 1:10 (5.71°) > FINGER GLUED JOINT WITH FINGER LENGTH 40mm, PITCH 9mm, and TIP WIDTH 1.0mm > PLAIN SCARF GLUED JOINT WITH SLOPE 1:12 (4.76°) > FINGER GLUED JOINT WITH LENGTH = 50mm, PITCH = 12mm and TIP WIDTH = 2.0mm > VERTICAL COMPONENT GLUED JOINT WITH SLOPE 1:8 (7.13°) > FINGER GLUED JOINT WITH LENGTH = 55mm, PITCH = 12.5mm and TIP WIDTH = 1.5mm > VERTICAL COMPONENT GLUED JOINT WITH SLOPE 1:12 (4.76°).

The modulus of Elasticities of the test samples reveals that in relation to the controlled sample which is 18,666.67N/mm^2 two types of joints, plain scarf with slope 1:10 (30,000N/mm^2) and finger joint with finger length 40mm, Pitch 9mm and Tip width 1.0mm (22,777.78N/mm^2) are stiffer while the remaining six (6): finger glued joint with finger length 55mm, pitch 12.5mm, and tip width 1.5mm (11,333.33N/mm^2); finger joint L=50mm, P=12mm and t=2mm (13,750N/mm^2); vertical component joint slope 1:12 (17,500N/mm^2); vertical component joint slope 1:8 (7,083.33N/mm^2); plain scarf glued joint slope 1:12 (15,571N/mm^2) and plain scarf glued joint slope 1:8 (17,865.47N/mm^2) are more flexible because the above given stresses are modulus of elasticity values.

Modulus of elasticity of a material is the ratio of stress to strain within the elastic limit and the higher the value the stiffer the member is said to be and the lower the value, the flexible the member is said to be. The above is therefore deduced by comparing the value of M.O.E. of the controlled pieces to the various glued joints. Ref. 4.5.1.

The mean densities of the nine types of samples used for the compressive strength tests range from 767.08Kg/m^3 to 867.19Kg/m^3 with the control sample having the mean density of 814.97Kg/m^3. The above variability of densities of test pieces confirm that timber, in this case mahogany exhibits non-homogenuity in density, colour and moisture returning capacity, variation in porosity and the presence of spiral cross-grains. For further variability of timber species Ref. to 4.5.1.

The mean moisture content of the forty (40) samples used for the compressive strength test is 9.89% which show that the samples were dry (M.C. 12% at R.H. of 65% at 20°C).

In compression parallel to grain, failure patterns were mostly shearing (plane of rupture at acute angle with the horizontal), then some splitting and few were crushed (plane of rupture approximately horizontal) as sketched in fig. 1.7(a) to (e) and failure modes were recorded against each sample piece in Table 4.2.1. Short (Ncrit/Nuz and l_e/b equal or less than 15 fifteen) wooden members, under compressive loading behave peculiar to itself as an isotropic material, with no definite yield point, and considerable set takes place before failure[x].

Short wood under compressive loading with appreciable increases fail by crushing, separation into columnar fragments or splitting or by various modes along its various strength zones and weakling aligned series of tubes or columns in the direction of the grain. Failure patterns exhibited in compression parallel to grain test by various specimens stated in Table 4.2.1 is further explained in Table 4.2.1.1.

4.5.3 **TENSION PARALLEL TO GRAIN**

The tensile strength of wood is relatively very high comparable to other properties. The test is difficult to perform due to the very high tensile strength of timber, it is difficult to grip the material (without crushing the grain and failure is usually in shear at the end of the waisted region rather than in tension within the waisted region for small clear specimen; 300 x 20 x 6mm, waisted in the central region to 6mm x 3mm.

Alot of the samples prepared for this test couldn't be tested because the testing machines in the Engineering Laboratories here in Zaria were unable to grip the fabricated glued specimens. The machines could only grip small sizes of samples, which were very difficult to form glued joints.

Clear samples of 30 x 30 x 450mm and single shear glued joints of the same size were finally experimented upon. The clear samples were fairly tested but the angular gripping of the single shear lap glued joints lead to premature tearing of test samples along the glue line. In view of the above the test were

considered to assess the tensile strength of the clear samples comparative with the bending strength of timber so used only.

The tensile stress at maximum load obtained 43.47N/mm^2 is higher than the bending stress 35.64N/mm^2.

In the bending mode timber is subjected to compression stresses on the upper part of the beam and tensile on the lower part[13]. Since the strength of clear timber in compression is only about one-third that in tension (Illston, 1979, pp 459 Section 14.8.1.3), failure will occur on the compressive side of the beam long before it will do so on the tension side, however it can be the reverse in knotty timber.

Values of tensile stress and compressive of this study did not follow the above 1:3 because the stresses are purely average experimental values and are "unpurified basic stresses" Ref. 4.5.4 and 4.5.5.

Table 104 of BS5291 and Table 105 of BS 4169 for finger joints and plain scarf joints have the same efficiency rating in bending and tension parallel to grain. In view of the above we shall adopt all the properties' values of our glued joints samples in bending for tension as they further satisfies the criteria that joints should have profiles either on the face or edge of rectangular sections, with at least four complete fingers present and gluing according to relevant glue manufacturer's gluing instructions and relevant codes.

4.5.4 VARIATIONS OF RESULTS

For purposes of design the most important properties of timber are modulus of elasticity, modulus of rupture, compressive stress at maximum load and tensile stress at maximum or ultimate load and invariably moisture content.

The variation of coefficient show the spread or scattering of the results. For static bending test the modulus of rupture results, the mean variation of result is 0.16 ± 0.11 (16% ± 11%), while the modulus of elasticity (M.O.E) is 0.45 ± 0.16 (45% ± 16%).

In compression parallel to grain test, test, the scattering of the compressive stress at ultimate load result is 0.13 ± 0.06 (13% ± 6%), where the modulus of elasticity (M.O.E) spread 0.31 ± 0.14 (31% ± 14).

The coefficients of variation for the modulus of rupture (M.O.R) and compressive stress at maximum load values are okay for many biological applications and design purposes. Rather high coefficients of variability are observed for the values of modulus of elasticity for all the tests' samples.

This can be attributed to the strength and modulus of elasticity values obtained, are purely average experimented timber sawn/construction wood sizes' values, and not the actual dry basic stress values which are obtained by applying safety factors to experimental values to take account of the variability in strength, the duration of load and the possibility of accidental over load. The other reasons are the non-homogenuity

of the wood in density, colour and moisture returning capacity (cell lengths and microfibrillar angle of S_2 layer within a growth ring), variation in porosity and the presence of spiral cross-grains produced naturally in the living tree. The gluability factors: The type of wood or wood products. The way the wood is cut and used (instruments and skills). The surface quality of the wood or wood product. The adhesive. The bending process. The type of joint. The service environment. The angle of the load to the direction of the grains and the glue line.

4.5.5 COMPARISON WITH OTHER WORKS

A close research work by Sarki (1991) in Civil Engineering, A.B.U., Zaria on "The Determination of Strength Properties of Three Nigerian Hard Woods" presents a good data on mahogany (Khaya-Senegalensis) dry-zone which is worth mentioning..

Results values of Table 4.9 show interesting comparisons. The strength values of this research (Timber sawn/construction timber sizes) and these obtained by Sarki P.U. 1991 on Small Clear Specimens of Timber were very close especially for density, moisture content and compressive stress at maximum load, loaded parallel to grain.

Results of this research for static Bending test; modulus of rupture are one-third of that of small clear timber (27.83N/mm^2 to 89.43N/mm^2).

The strength values of this research are inbetween those of small clear specimens of timber and those of NCP 2: 1973 and B.S.

5756/BS 5268: Part 2: 1984, but very close values for density, moisture content and modulus of elasticity.

The values of modulus of rupture (M.O.R)

Table 4.9: Comparison of Results on Khaya-Senegalensis. Small Clear Specimens and Sawn Timber/Construction Timber Sizes Specimens

	Static Bending					Compression Parallel to Grain			
Specimen stress at (U.L.)	Density	Moisture Content at Test	Fibre Stress at L.P.	Modulus of Rupture	Modulus of Elasticity	Density	Moisture content at Test	Compressive stress at at L.P.	Compressive at Max Load
	Kg/m³	%	N/mm²	N/mm²	N/mm²	Kg/m³	%	N/mm²	N/mm²
Khaya Senegalensis (1991 Research)	772.43	13.1	64.50	89.43	12,500	772.43	13.6	-	46.78
FINGER GLUED JOINTS:									
L=55,P=12.5 & t=1.5mm	798.28	13.01	7.0	33.70	5,648.15	814.89	8.55	5.18	45.27
L=50, P = 12 & t= 2mm	791.29	15.43	6.76	26.29	6,619.05	804.71	10.05	7.9	51.25
L=40, P = 9 & t = 1mm	757.63	13.03	3.0	21.53	2,347.22	845.90	9.38	8.8	53.08
PLAIN SCARF GLUED JOINTS:									
Slope 1:12	777.32	13.90	4.92	33.68	4,791.67	834.91	9.90	9.07	53.01
1:10	789.10	10.98	2.30	30.96	2,848.48	854.01	10.51	6.75	56.19
1:8	779.49	15.43	6.27	27.58	5,694.45	867.19	9.31	12.9	59.61
PARTIAL INTEGRAL GLUED JOINTS:	821.34	10.76	3.72	13.25	3,541.67	-	-	-	-
VERTICAL COMPONENT GLUED JOINTS:									
Slope 1:12	-	-	-	-	-	767.08	13.3	5.67	43.84
1:8	-	-	-	-	-	767.64	8.51	6.5	46.43
CLEAR SPECIMENS (CONTROLLED PIECES)	792.25	13.93	5.24	35.64	6,004.76	814.97	10.52	11.1	60.66
NCP2: 1973 TABLES 10/2 VALUES FOR N3.GRD 80 (FACTORED)	816.0	≤ 18.0	-	18.0	10,600	816.0	≤ 18.0	-	14.0
BS5756 HS GRADE 8.76 AFRICAN MAHOGANY	590/760	DRY GRADE (12.0%)	-	8.69	9,400	590/760	12.0	-	

in static bending test (mean 27.83N/mm^2) and that of compressive stress at ultimate load in compression parallel to grain test (mean 52.15N/mm^2) are far greater than those in NCP2 and BS 5756 (18N/mm^2 and 8.69N/mm^2, and 14.0N/mm^2 and 8.76N/mm^2 respectively). There is this difference because the research has produced "unpurified basic stresses" not multiplied by a value known as strength ratio (or factor). The safety factor purify the basic stress value obtained from tests from the nature and extent of the defects permitted for particular grades, where timber pieces containing defects are carefully recorded.

Grade stresses derived from full structural sizes test is done by estimating a minimum value for each grade, in a similar way to the estimation of statistical minimum strengths from small clear specimens, and then by dividing by a reduction factor which adjusts to a standard size, duration of load and exposure condition, and incorporates a factor of safety.

4.5.6 STRESS-STRAIN EQUATIONS

Knowledge of regression analysis was used to compute the equations for the approximating curves from the stress-strain plotted data for Fig: (a) flexural to Fig: (h) flexural, Fig: (a) compression to Fig: (i) compression, Fig: (a) Tension and Fig: (b) tension.

The equations of the lines or curves of best fit will enable us to predict the value of strain on stress and vice versa for Bending (flexural) and tensile loading systems and compressive

loading systems in timber design and constructions.

Recall the simplest form of nonlinear function for the regression of Y on X, Equations 5, 6 and 7 from section 4.4.

$$E(y/x) = \alpha + ß\, g(x) \quad (5)$$

$$E(y/x) = \alpha + ß_1 x + ß_2 X^2 + \ldots\ldots + ß_m X^m \quad (6)$$

$$E(y/x) = \alpha + ß_1 Z_1 + \ldots\ldots + ß_m Z_m \quad (7)$$

Let stress (σ) be the dependent variable and strain (ϵ) be the corresponding variable.

The following stress strain Equations were derived for all Tests joints:-

Flexural Test

1. Finger joint, length = 55mm, Pitch 12.5mm and Tip width = 1.5mm Fig: (1) Appendix 2.

   $\sigma = 0.487 + 0.010\epsilon - 8.409 \times 10^{-7}\epsilon^2$

   Has a standard normal distribution shape.

2. Finger glued joint; L = 50mm, P = 12mm and t = 2mm Fig: (b).

   $\sigma = 2.127 + 0.011\epsilon - 3.761 \times 10^{-6}\epsilon^2 + 6.016 \times 10^{-10}\epsilon^2$

3. Finger glued joint; L = 40mm, P = 9mm and t = 1.0mm Fig: (c).

   $\sigma = -0.015 + 0.003\epsilon + 2.486 \times 10^{-7}\epsilon^2$

   Half shape of standard distribution.

4. Scarf glued joints: Slope 1:12 Fig: (d).

   $\sigma = -1.201 + 0.005\epsilon + 3.236 \times 10^{-7}\epsilon^2 - 3.634 \times 10^{-11}\epsilon^3$

   Shape of standard normal distribution.

5. Scarf glued joints: Slope 1:10 Fig: (e).

$\sigma = -0.448 + 0.005\epsilon + 9.009 \times 10^{-7}\epsilon^2 - 1.863 \times 10^{-10}\epsilon^3$

Shape of standard normal distribution.

6. Scarf glued joints: Slope 1:8 Fig: (f).

$\sigma = 10.815 - 0.012 + 9.917 \times 10^{-6}\epsilon^2 - 1.549 \times 10^{-9}\epsilon^3$

Sinusoidal shape-shell structure behaviour.

7. Partial Integral glued Timber joints. Fig: (g).

$\sigma = 1.48 + 0.033\epsilon + 2.896 \times 10^{-5}\epsilon^2 + 6.555 \times 10^{-9}\epsilon^3$

Sinusoidal shape-shell structure behaviour.

8. Clear specimen (controlled pieces) Fig: (h).

$\sigma = 4.756 + 0.001\epsilon + 2.264 \times 10^{-6}\epsilon^2 - 2.821 \times 10^{-10}\epsilon^3$

Has standard normal distribution shape.

COMPRESSION TEST PARALLEL TO GRAINS

(a) finger glued joint, L = 55mm, P = 12.5mm and t = 1.5mm Fig: (a) Appendix 2.

$\sigma = 2.318 + 0.015\epsilon - 1.393 \times 10^{-6}\epsilon^2$

second degree polynomial.

The curve is of density function of the standard normal distribution.

(b) Finger glued timber joint: L = 50mm, P = 12mm and t = 2mm Fig: (b).

$\sigma = 5.334 + 0.012\epsilon - 7.822 \times 10^{-7}\epsilon^2$

The curve has a standard normal distribution shape.

(c) Finger glued timber joint: L = 40mm, P = 9mm and t = 1mm Fig: (c).

$\sigma = 0.693 + 0.021\epsilon - 2.254 \times 10^{-6}\epsilon^2$

The curve has standard normal distribution outlook.

(d) Vertical component glued timber joints: with 1:12 Slope Fig: (d).

$\sigma = -0.845 + 0.016\epsilon - 1.544 \times 10^{-6}\epsilon^2$

The curve has standard normal distribution function shape.

(e) Vertical component glued timber joint: width 1:8 Slope Fig: (e)

$\sigma = -2.127 + 0.014\epsilon - 1.183 \times 10^{-6}\epsilon^2$

Standard normal distribution function shape

(f) Plain scarf glued timber joints: Slope 1.12 Fig: (f).

$\sigma = 0.618 + 0.016\epsilon - 1.090 \times 10^{-6}\epsilon^2$

Standard normal distribution shape.

(g) Plain scarf glued timber joints, with slope 1:10 Fig: (g).

$\sigma = 1.048 + 0.019\epsilon - 1.040 \times 10^{-6}\epsilon^2$

The curve turns towards standard normal distribution shape.

(h) Plain scarf glued timber joints. With slope 1:8 Fig: (h) Appendix 2.

$\sigma = -0.997 + 0.020\epsilon - 1.346 \times 10^{-6}\epsilon^2$

Curve turning towards standard normal distribution shape.

(i) Clear specimen (controlled pieces) Fig: (i).

$\sigma = -0.382 + 0.018\epsilon - 9.761 \times 10^{-7}\epsilon^2$

The curve is half shape of standard normal distribution model.

It is observed that all Equations are of the second degree

polynomial with standard normal distribution shape.

TENSION TEST PARALLEL TO GRAIN

(a) Single shear lap glued joint lapping length > 5 thickness mm (8t) Fig: (a).

$\sigma = 2.232 + 0.010\epsilon - 3.630 \times 10^{-6}\epsilon^2$

Has standard normal distribution shape.

(b) Clear specimens (controlled pieces) Fig: (b) Appendix 2.

$\sigma = 0.557 + 0.017\epsilon - 1.251 \times 10^{-6}\epsilon^2$

Has standard normal distribution shape.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the study carried out on five (5) types (ten 10) different glue joint profiles) of timber glued joints, the following conclusions are drawn from the analysis and discussion of tests results:-

1. For flexural (bending) and Tensile loading systems in timber construction, results indicate clearly that Finger glued timber joint with 55mm length, 12.5mm pitch and 1.5mm tip width is most efficient. Below are the various joints arranged in the order of efficiency, the most efficient (94.6% Efficiency) at the top and the least efficient (37.2% Efficiency) at the bottom.

   FINGER GLUED TIMBER JOINT 55mm length; Pitch 12.5mm and Tip width 1.5mm > PLAIN SCARF GLUED TIMBER JOINT WITH SLOPE 1:12 (4.7°) > PLAIN SCARF GLUED TIMBER JOINT WITH SLOPE 1:10 (5.71°) > PLAIN SCARF GLUED TIMBER JOINT WITH SLOPE 1:8 (7.13°) > FINGER GLUED TIMBER JOINT WITH L = 50mm, P = 12mm and t = 2mm > FINGER GLUED TIMBER JOINT WITH L = 40mm, P = 9mm and t = 1.0mm > PARTIAL INTEGRAL GLUED TIMBER LAP JOINT, Lapped 150mm long.

2. For compression parallel to grain in timber construction, the results show that plain scarf glued timber joint of slope 1:8 is most efficient. Types of timber glued joints

arranged below for the loading system are in the order of efficiency, the most efficient (98.3%) at the top with the least efficient (72.3%) at the bottom.

PLAIN SCARF GLUED TIMBER JOINT WITH SLOPE 1:8 (98.3%) > PLAIN SCARF GLUED TIMBER JOINT WITH SLOPE 1:10 (92.6%) > FINGER TIMBER GLUED JOINT WITH FINGER LENGTH 40mm, PITCH 8mm, and TIP WIDTH 1.0mm (87.5%) > PLAIN SCARF TIMBER GLUED JOINT WITH SLOPE 1:12 (87.4%) > FINGER TIMBER GLUED JOINT WITH LENGTH 50mm, PITCH 12mm and TIP WIDTH 2.0mm (84.5%) > VERTICAL COMPONENT TIMBER GLUED JOINT WITH SLOPE 1:8 (76.5%) > FINGER TIMBER GLUED JOINT WITH LENGTH 55mm, PITCH 12.5mm and TIP WIDTH 1.5mm (74.6%) > VERTICAL COMPONENT TIMBER GLUED JOINT WITH SLOPE 1:12 (72.3%).

3. The efficiencies of glued joints obtained from this study for finger glued joints and plain scarf glued joints confirm Rivers, 1987, work on classification of selected wood species according to ease of bonding. The said work mentions African Mahogany as Bonding well with fairly wide range of adhesives under a moderately wide range of bonding conditions.[22] The joints are therefore recommended for timber construction in Nigeria and with good workmanship the glued joints of this study could compare favourably with laminated beams and columns (Portal frames) as far as strengths are concerned. As economy is concerned, the glued timber joints are cheaper. Production is not limited to factories.

4. The density of the experimental timber specie conform to N3

strength groups for Nigeria timbers. Table 2 and 8 of NCP2: 1973.

5. Properties, preparation and application (physical features) of cascamite powdered synthetic resin glue used in the study indicate that it belongs to the inorganic thermosetting major group of adhesives. The glue can be speculated to be either Urea - resin (Urea-formaldehyde) or melamine-resin (melamine-formaldehyde).

6. If cascamite powdered resin glue is Urea-formaldehyde MR/UF, melamine-formaldehyde MR/MF or melamine formaldehyde/Urea-formaldehyde BR(MF/UF), then it is moisture resistant (or moderately weather-resistant) or Boil-Resistant. The adhesive used in the study is therefore suitable for exposure condition of exterior low hazard and Interior low hazard for wood not exceeding 18% moisture content and glue line below 50°C). According to the usable life of cascamite powdered resin is reduced at higher temperatures. This area calls for further investigation.

7. The results of this study indicate that African mahogany (especially Khaya - Senegalensis) can conveniently be glued using resin contrary to publication by Timber Research and Development Association, London - Mettem, 1986. The above publication names INT Casein as the only, glue type suitable for gluing African mahogany.

8. In static bending (that is with 4-point loading method), the modulus of rupture (MOR) as obtained by loading at third

points (BS 5291: 1984) is twice that obtained by loading at one-sixth points (BS 373: 1957) from supports. The two loading systems are therefore acceptable for this study.

9. Equations in section 4.5.6 have been proposed to predict the stress - strain relations of the five (5) mahogany glued joints (ten (10) mahogany glued joints profiles), in this study.

5.2 RECOMMENDATIONS

"Efforts are underway in the United States of America (U.S.A) and in Europe to develop design methods and standards for structural glued assembly joints, but as yet there are no standards". Reported by River B.H. 1992, Research Scientist, Wood Adhesive Science and Technology, United States Department of Agriculture, Forest Product Laboratory Madison. The above is a bedrock for more research in this area.

1. As of today few resin glues and unclassified Emulsion white glues are manufactured locally, efforts should be made to manufacture phenol-formaldehyde, Resorcinol resin and phenol-resorcinol formaldehyde (dark red in liquid or powdered form). They are very suitable for exterior high hazard exposure conditions.
2. Manufacturers of adhesives and preservatives should work together and produce list of brands of adhesives that are compatible with preservatives to enhance wider acceptability

and usage in timber construction.

3. The Federal Government of Nigeria and corporate bodies should establish at least five (5) centres in the country, including the Forestry Research Centre at Ibadan and equip them with modern timber glue jointing equipments; finger and scarf jointing equipments, containing: Trim saw; cutter (or shaper) head; and glue applicator, low voltage and high frequency curing adhesive mechanisms, grips testing machines and Electronic Universal testing machine capable of plotting stress - strain curves.

4. Very serious research activities should be carried out on the glue performance on Nigerian timbers or the suitability of some important Nigerian woods with adhesive types involving all exposure conditions with corresponding adhesive performance types and efficiency of glued joints with aging time. Such research and this study will lead Nigeria onto compiling design methods and standards for structural glued assembly joints!

REFERENCES

1. American Society for Testing and Materials (ASTM): 1958, Part 6. "Wood-paper, Adhesives Shipping Containers, Cellulose", ASTM Philadelphia.

2. Ang, A.H.S. and Tang, W.H. 1975. "Probability Concepts on Engineering Planning and Design". Volumes 1 - Basic Principles. John Wiley and Sons, Inc. New York. PP. 97-101 and PP. 287-328.

3. Booth, L.G. and Reece, P.O. 1967. "The Structural Use of Timber". A Commentary on the British Standard Code of Practice CP 112: 1967. E and F.N. Spon Limited, London. PP. 177.

4. British Standard 373: 1957. "Methods of Testing Small Clear Specimens of Timber". British Standard Institution, London. PP. 5, 8-10, 12-17, 19 and 29.

5. British Standard 5268: Part 2: 1984 "Code of Practice for Permissible Stress Design Materials and Workmanship". British Standards Institution, London. PP. 4, 14, 19, 82, 86, 90, 99 - 101.

6. British Standard 5291: 1984. "Manufacture of Finger Joints of Structural Softwood". British Standard Institution, London. PP. 2, 3, 9, 11, 14 and 15.

7. Cooper, D.W. 1968. "Timber Engineering". Structural Engineer. In: Harrison, D. 1968. "Specification 1968 Volume 1, 69th Year". The Architectural Press, London. PP. 1/472 - 481.

8. Davis, H.E. Troxell, G.E. and Wiskocil, C.T. 1964. "The Testing and Inspection of Engineering Materials". McGraw Hill Book Company, New York. PP 23 - 35, 116 - 123, 138 - 149, 165 - 178, 350, 351, 358 - 360 and 408 - 413.

9. Desch, H.E. 1956. "Timber, Its Structure and Properties". MacMillan and Co. Limited, London. PP. 116 - 125 and 306.

10. Everett, A. 1981. "Materials". Mitchells' Building Series. Batsford Academics and Education Limited, London. PP. 81, 282 - 287.

11. Great Britain 1959. "The Efficiency of Adhesives for Wood". H.M.S.O., Forest Products Research Laboratory, D.S.I.R., Bulletin No. 38. In: Tyler, R.G. 1962. "The Structural Properties of West African Timbers".

West African Building Research Institute, Accra - Ghana and Zaria - Nigeria. PP. 11 - 12.

12. Greer, A. 1979. "Statistics for Engineers". Stanley Thornes (Publishers) Limited Cheltenham, England. PP. 106 - 120.

13. Illston, J.M., Din woodie, J.M., and Smith, A.A. 1979. "Concrete, Timber and Metals". The Nature and Behaviour of Structural Materials VanNpstrant Reinhold Company, New York. PP. 374 - 376 and 431 - 440.

14. Kubler, H. 1980. "Wood as a Building and Hobby Material". John Wiley and Sons, New York. PP. 194 - 206.

15. Letcha, S.S. 1990/91. "MSc. Lecture Notes on Timber Technology". Civil Engineering Department, Ahmadu Bello University, Zaria, Nigeria.

16. Mettem, C.J. 1986. "Structural Timber Design and Technology". Timber Research and Development Association (TRADA). Longman Scientific and Technical, England. PP. 129 - 145 and 150.

17. Mosley, W.H. and Bungey, J.H. 1989. "Reinforced Concrete Design". MacMillan Education Limited, London. PP. 241 -243.

18. Nigerian Code of Practice (NCP) 2: 1973. "Structural Use of Timber". Nigerian Standard Organisation Publication, Lagos, Nigeria. PP. 6 - 42, 44, 59 - 60.

19. Okigbo, L. and Comben, A.F. 1965. "Standard Testing Procedure". Forest Products Research Laboratory, Federal Department of Forest Research, Ibadan, Nigeria. PP. 7, 18, 19, 22, 26, 27, 86, 87 and 89.

20. Ozelton, E.C. and Baird, J.A. 1982. "Timber Designers' Manual". Ghana Publishing Limited, London. PP. 376.

21. Reece, P.O. 1949. "The Design of Timber Structures". E and F.N. Spon Limited, London. PP. 139, 206 - 212.

22. River, B.H. 1987. "Bonding Wood and Wood Products". In: Wood Handbook: "Wood as Engineering Material". Agriculture Handbook 72. Revision. United State Department of Agriculture, Forest Product Laboratory, Washington, D.C. PP. 9/1 - 9/20.

23. River, B.H. 1992. "Gluing of Wood and Use of Adhesive for Structural Purposes". Madison, United States of America. Personal Communication - Letter.

24. Sarki, P.U. 1991. "Determination of Strength Properties of Three Nigeria Hardwoods". Unpublished B. Eng. Thesis, Civil Engineering Department, Ahmadu Bello University, Zaria, Nigeria. PP. 50, 58 and 62.

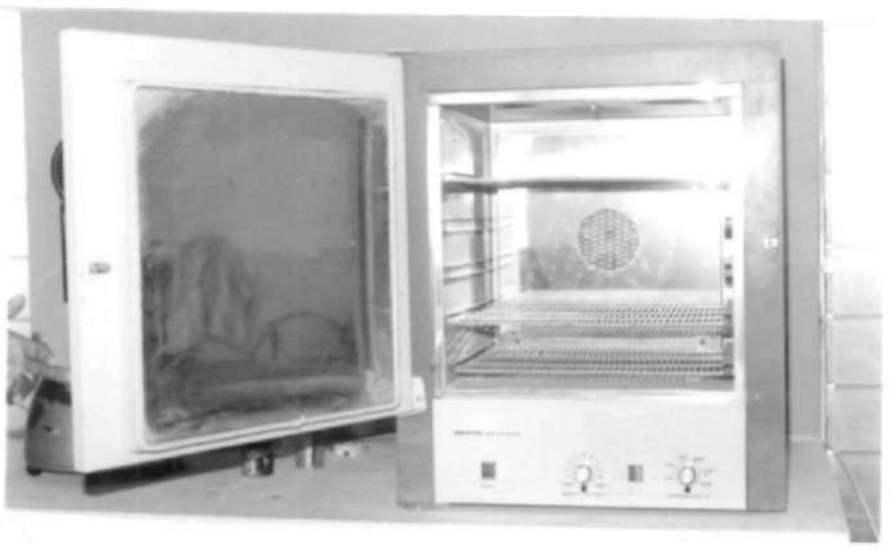
25. Selbo, M.L. 1975. "Adhesives Bonding of Wood". Technical Bulletin No. 1512, United States Department of Agriculture, Forest Service; Washington D.C. U.S.A. PP. 1, 8, 31, 49 - 51, 71 - 77, 83, 91, and 98 - 102.

26. Tyler, R.G. 1962a. "The Structural Properties of West African Timbers". West African Building Research Institute, Accra - Ghana and Zaria - Nigeria. PP. 14 - 15.

27. Tyler, R.G. 1962b. "Test on Joints in Timber Beams" (In Press). West African Building Research Institute. In: Tyler, R.G. 1962a. "The Structural Properties of West African Timbers". West African Building Research Institute, Accra - Ghana and Zaria - Nigeria. PP. 12.

28. White, N.C. "The Durability of Glues for Plywood Manufacture". Current Paper In: Building Research Establishment, No CP 84/75 P. 11 PP London.

APPENDIX 1: APPARATUS PLATES



VENTILATED GRIFFIN 300F COVEN (300°C CAP) OVEN



METTLER ELECTRONIC WEIGHING MACHINE

APPENDIX 2: SAMPLE GRAPHS

19N0s Stress-strain curves
19Nos Regression analysis: curves of best fit predicting stress-strain values for samples.

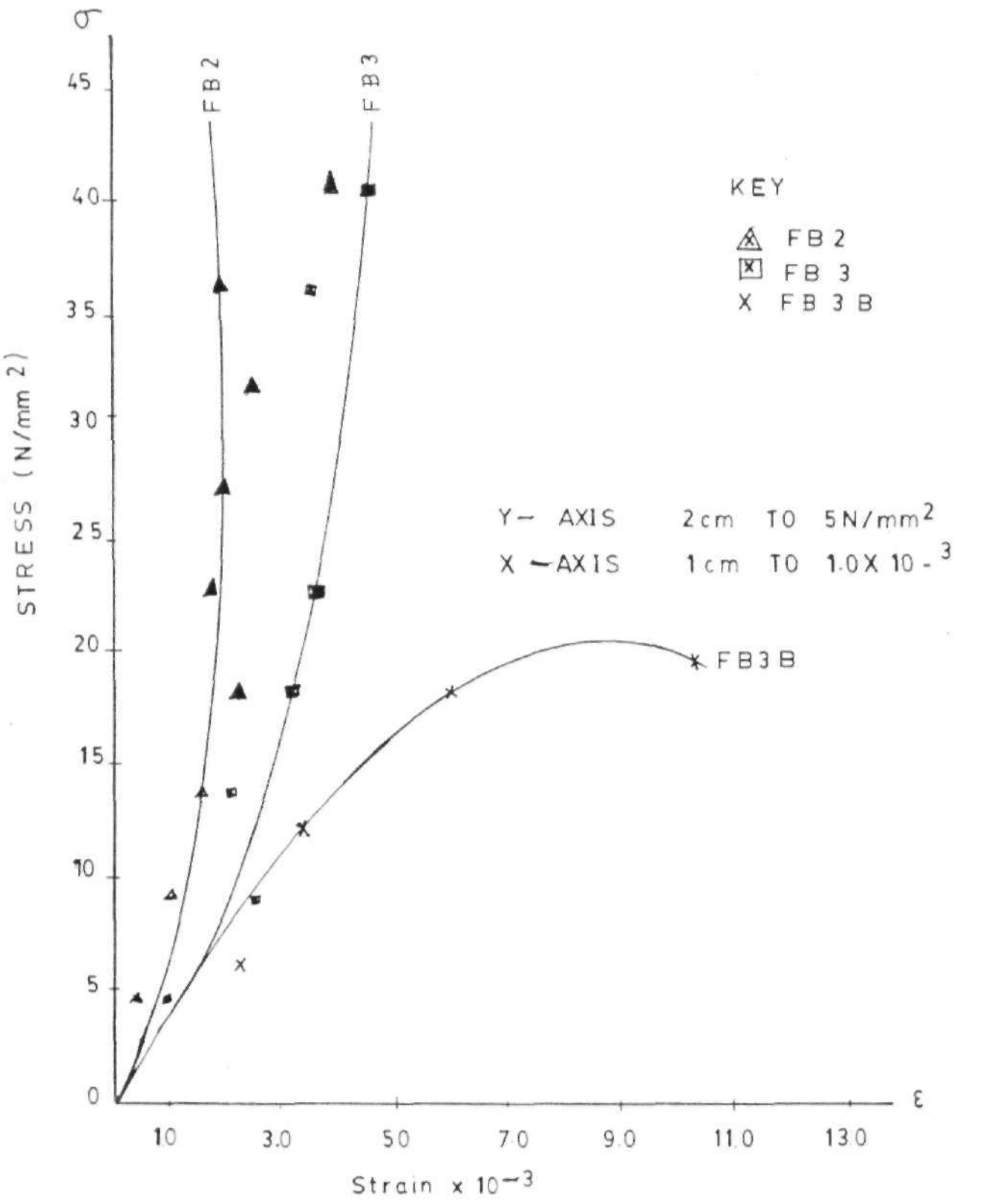


FIG: B.1 STRESS–STRAIN CURVES FOR TIMBER GLUED JOINTS FB 2 & 3 (55)

STATIC BENDING TEST RESULTS

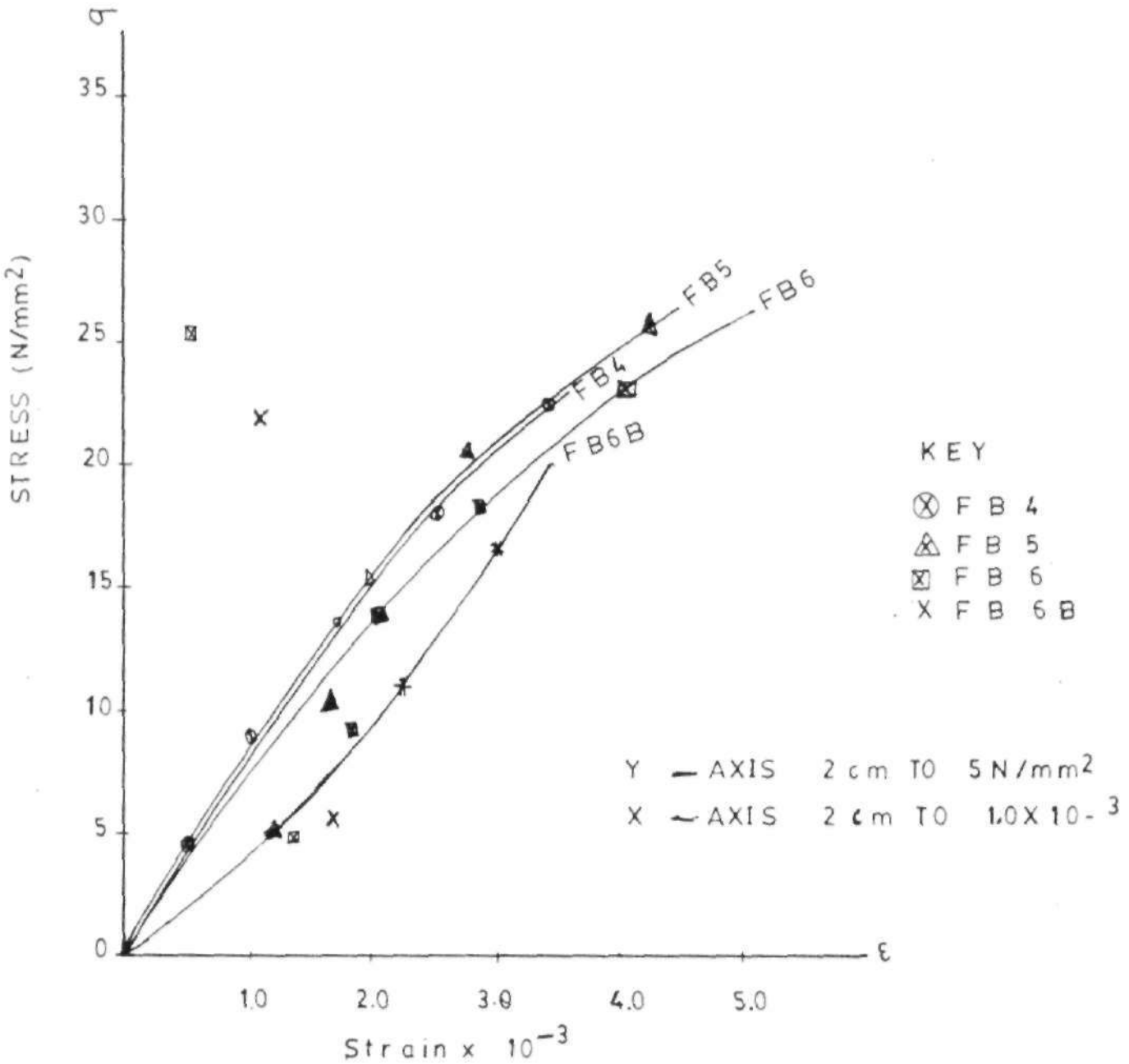


FIG: B-2 STRESS - STRAIN CURVES FOR TIMBER GLUED JOINTS
FB 4-6 (50)

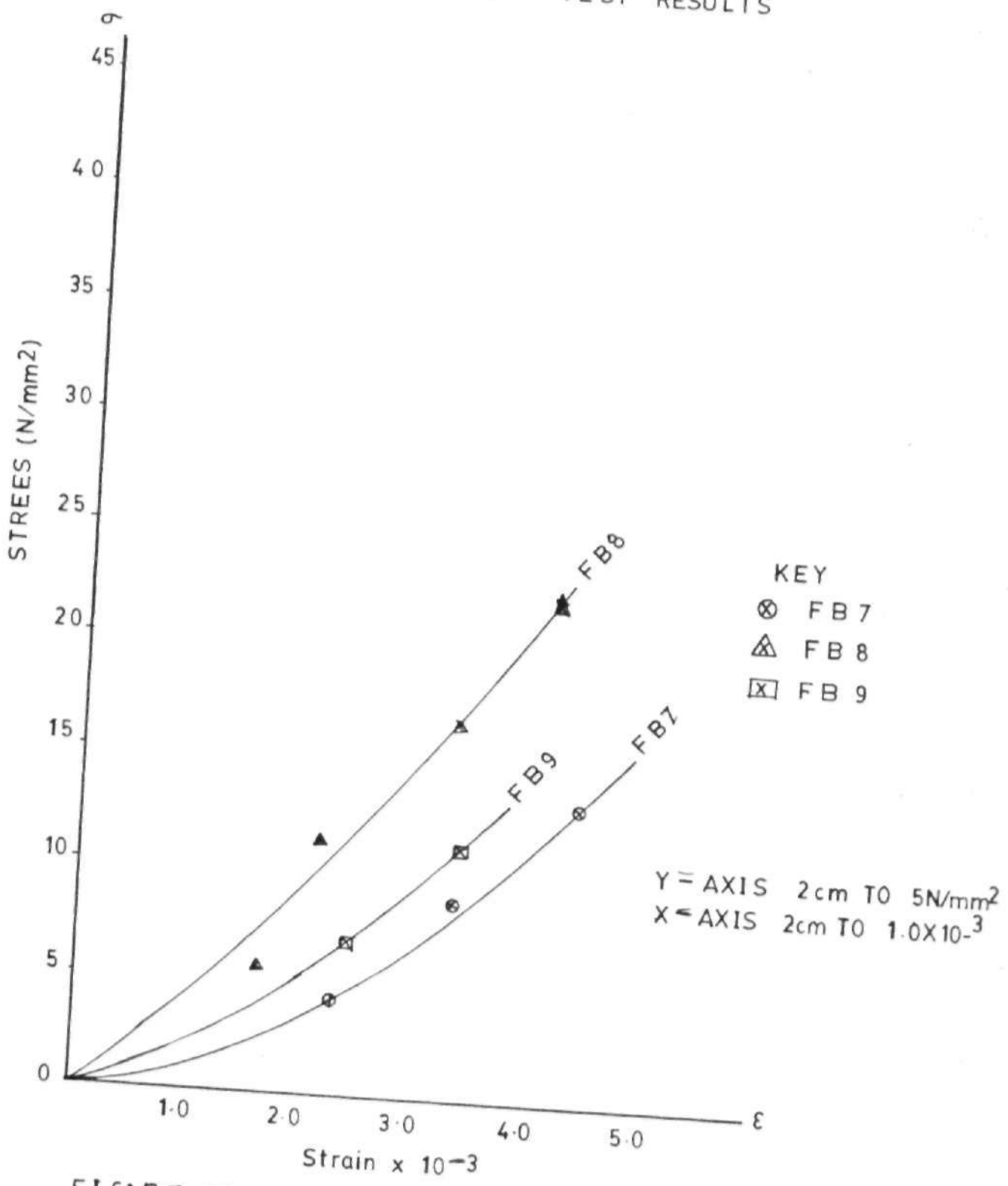


FIG:B.3 STRESS - STRAIN CURVES FOR TIMBER FINGER GLUEDJOINTS F B 7 – 9 (40)

STATIC BENDING TEST RESULTS

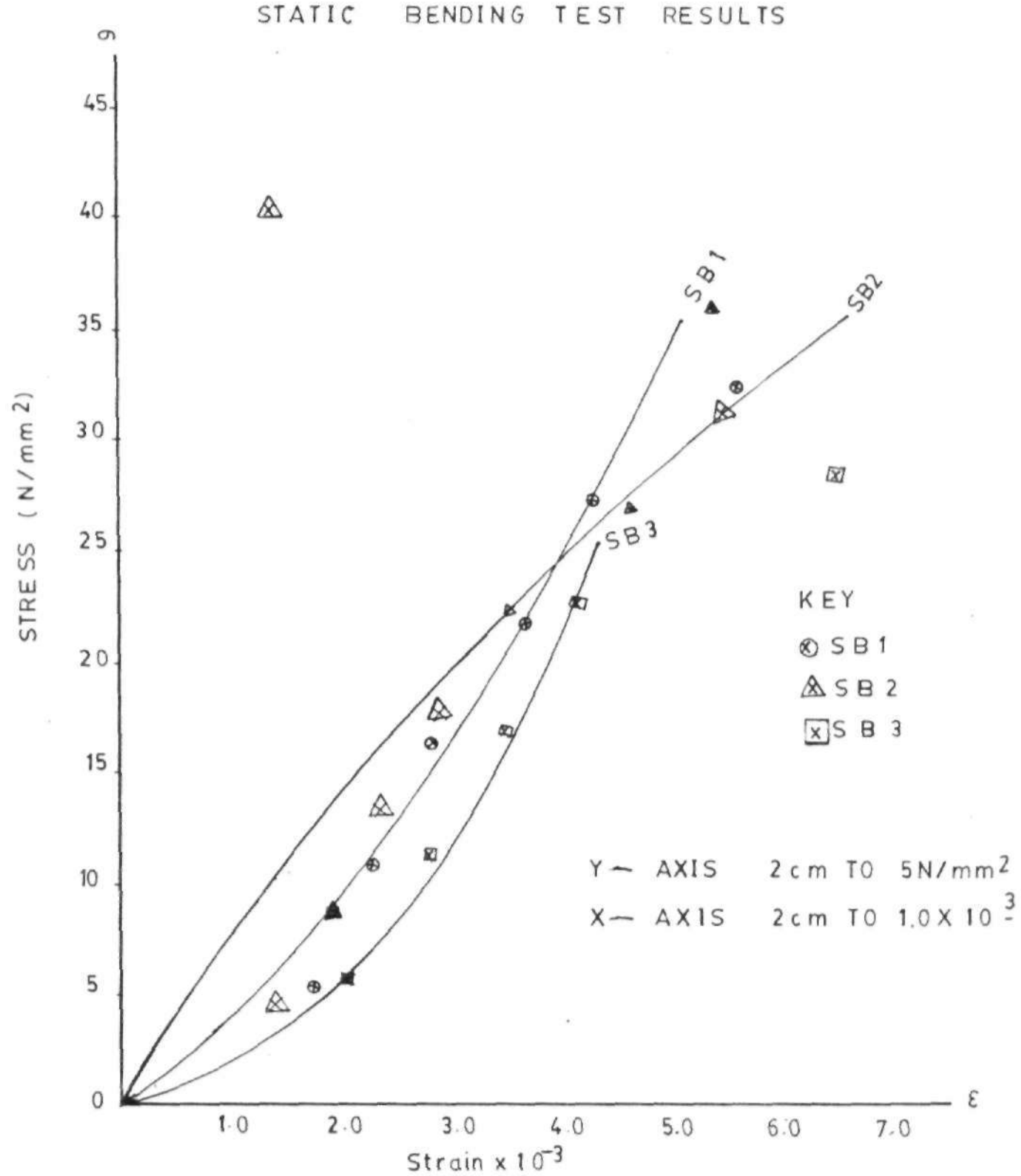


FIG:B.4 STRESS-STAIN CURVES FOR SB1-3 TIMBER SCARF GLUED JOINTS (1:12)

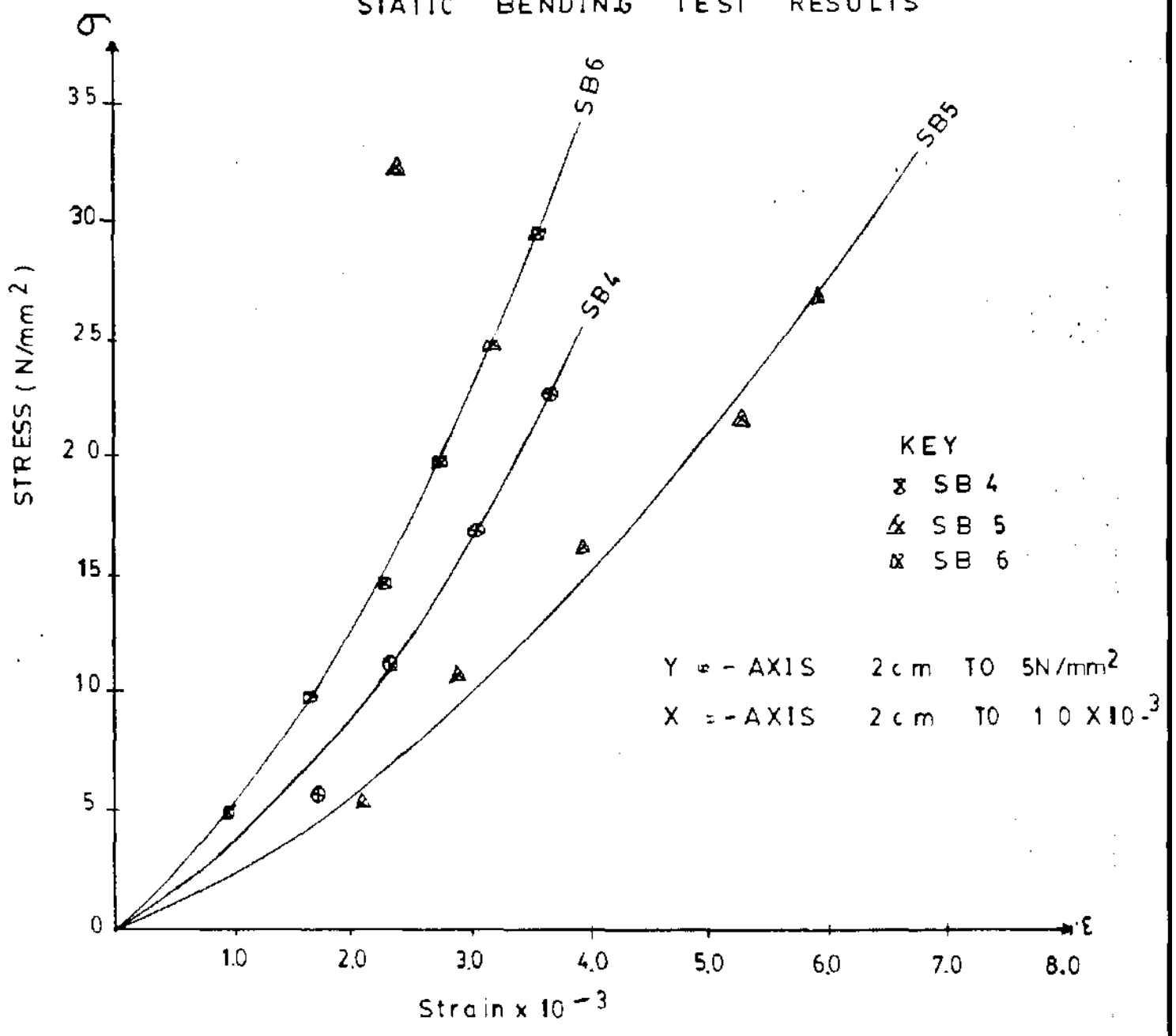


FIG:B-5 STRESS-STRAIN CURVES FOR TIMBER PLAIN SCARF JOINTS SB4 - 6 (1:10)

STATIC BENDING TEST RESULTS

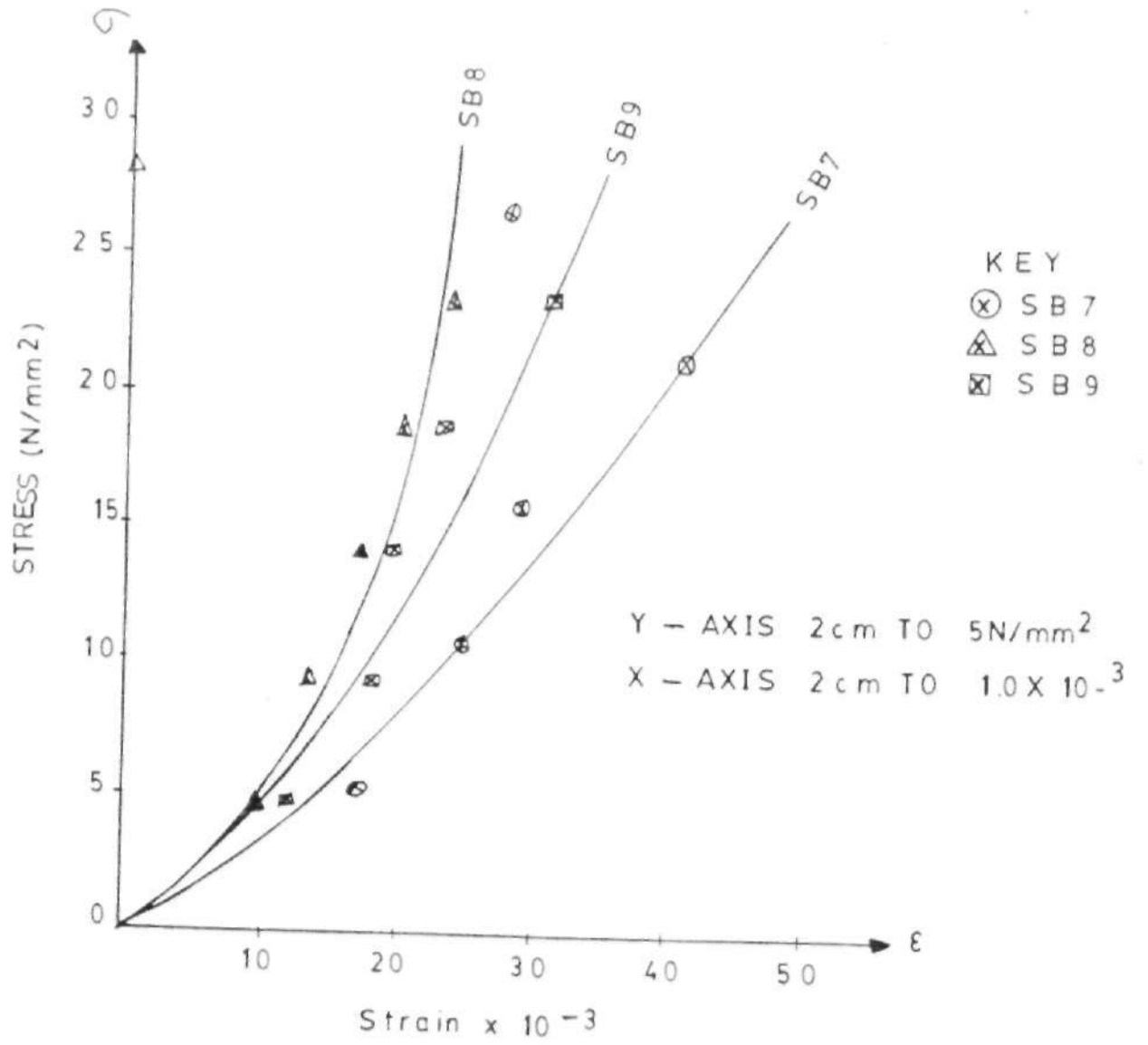


FIG:B·6 STRESS–STRAIN CURVES FOR TIMBER SCARF JOINTS SB 7-9 (1:8)

STATIC BENDING TEST RESULTS

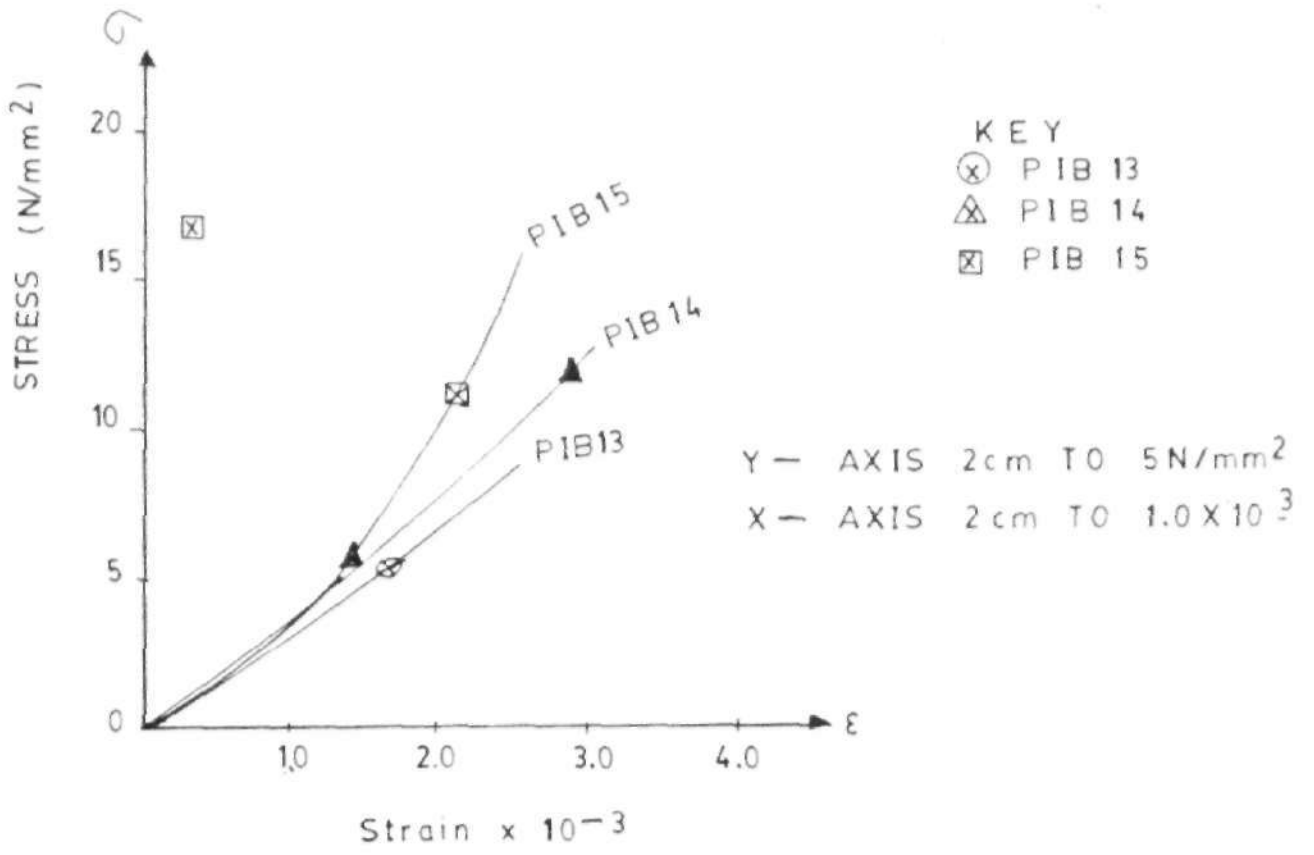


FIG: B·7 STRESS — STRAIN CURVES FOR TIMBER PARTIAL INTEGRAL GLUED JOINTS P1B 13–15 (15° LAPPED)

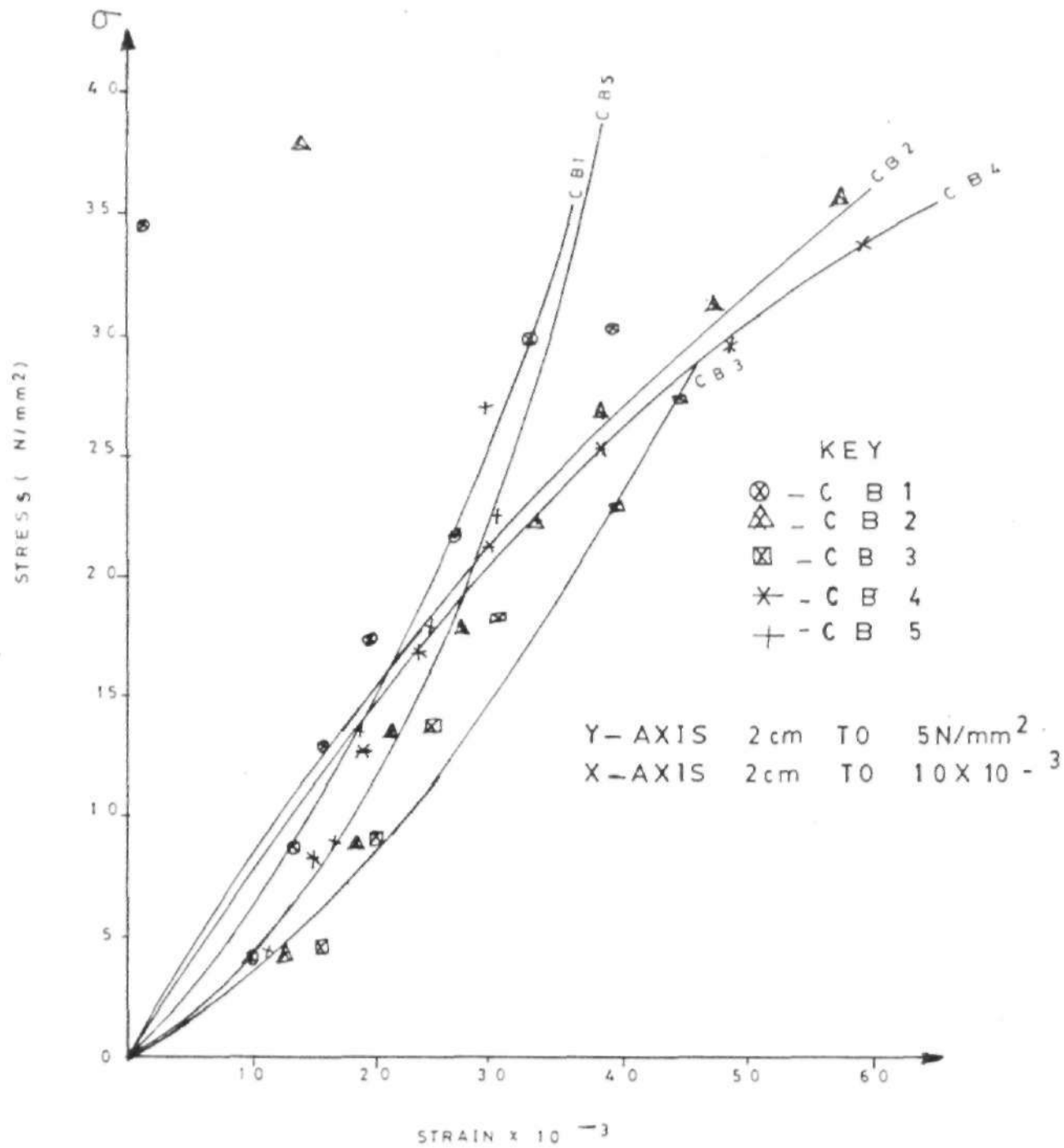


FIG:B-8 STRESS-STRAIN CURVES FOR TIMBER CLEAR SPECIMENS (CONTROL SPECIMENS)

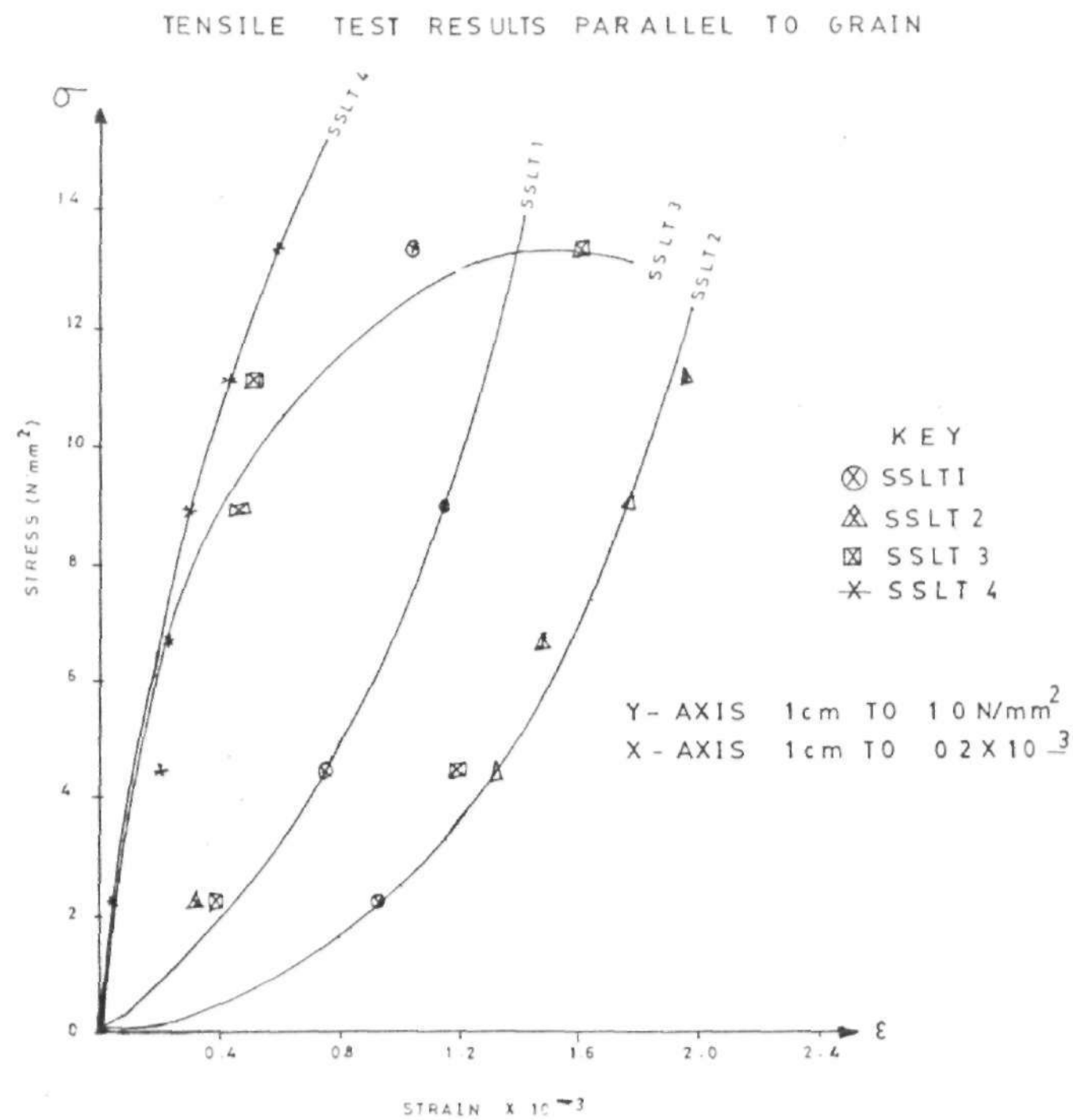


FIG:T-1 STRESS-STRAIN CURVES FOR TIMBER SINGLE SHEAR LAPPED GLUED JOINTS : SSLT 1 – 4

TENSILE TEST RESULTS PARALLEL TO GRAIN

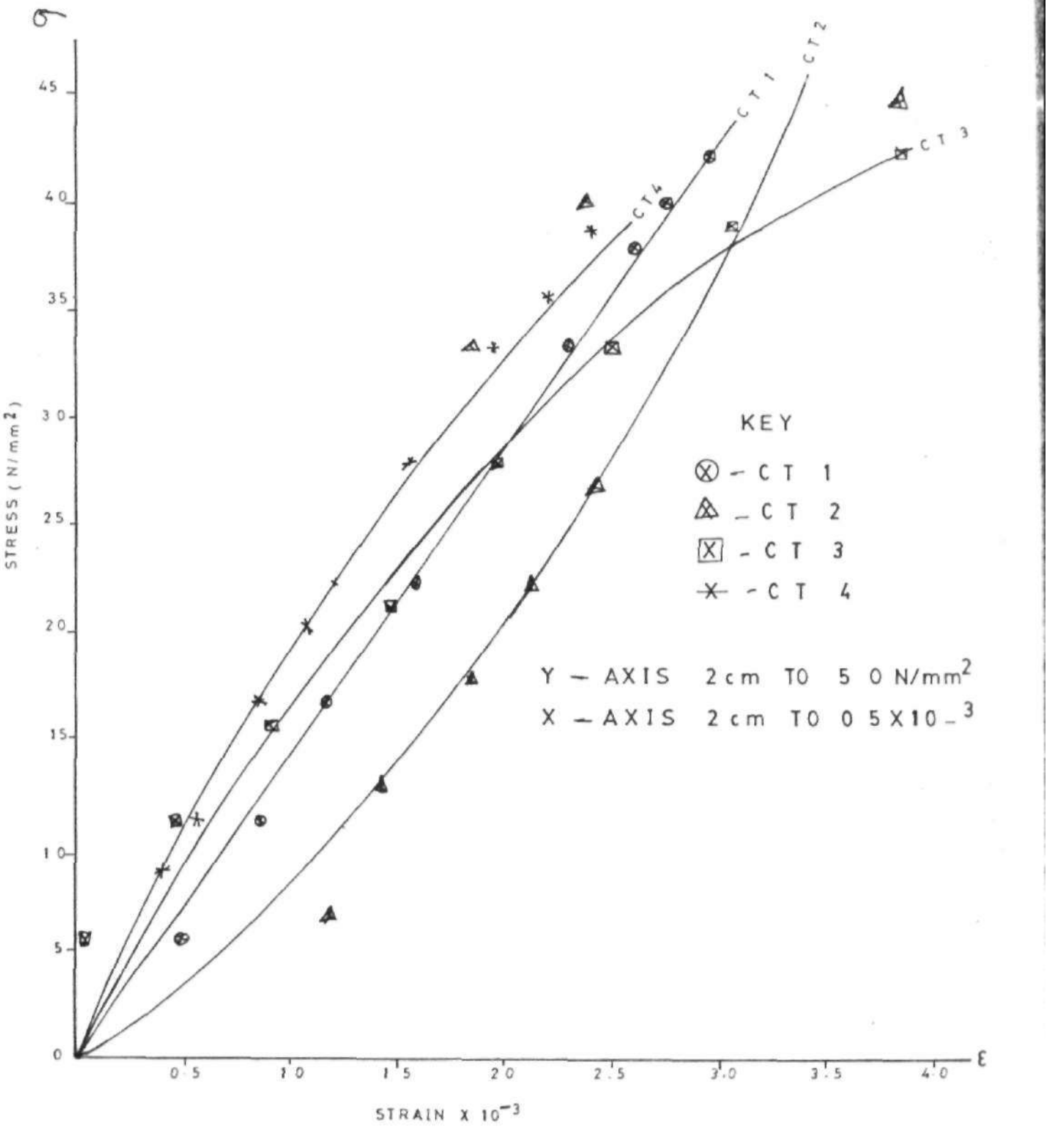


FIG:T-2 STRESS–STRAIN CURVES FOR TIMBER CONTROLLED SPECIMENS

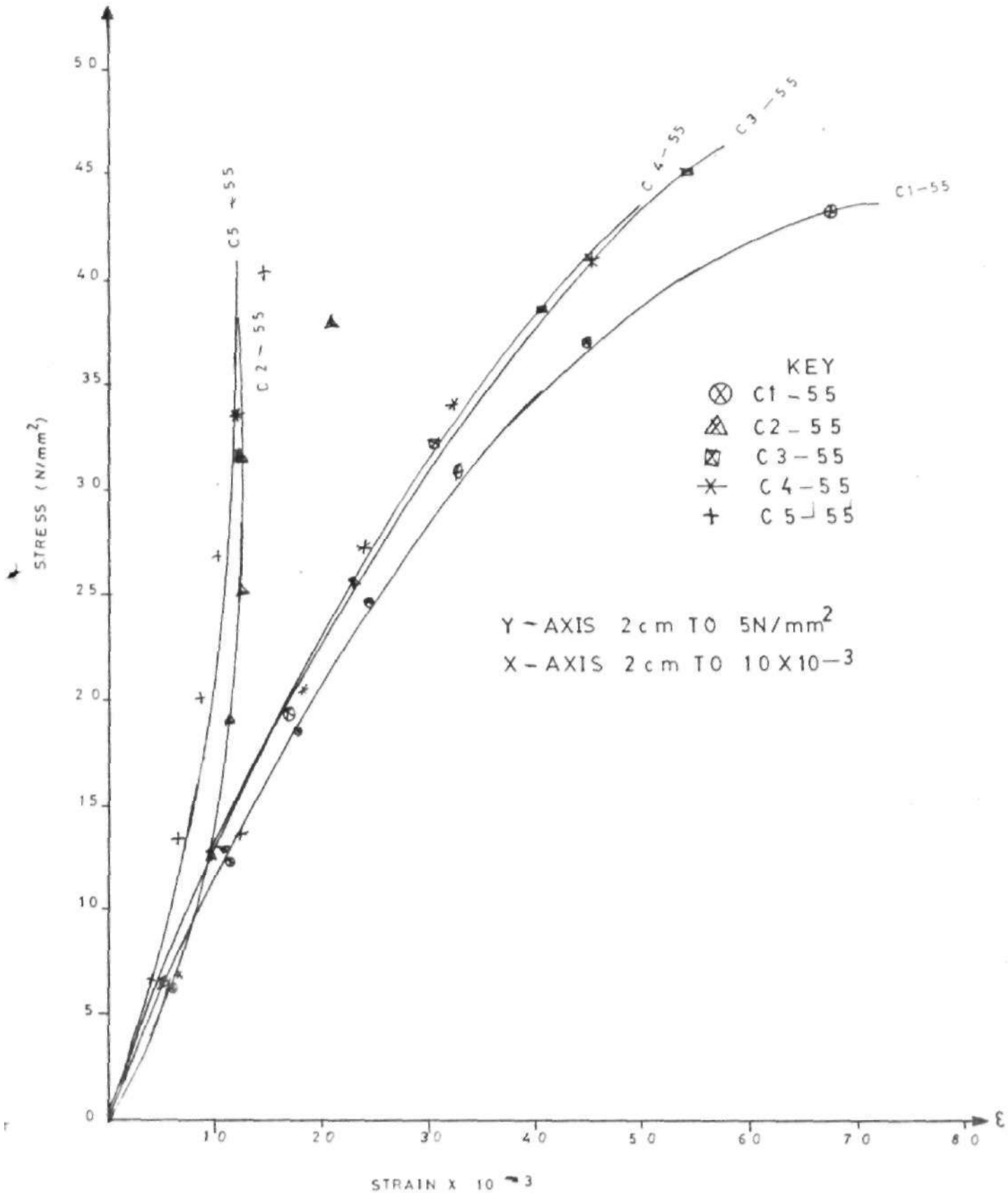


FIG:C-1 STRESS - STRAIN CURVES FOR TIMBER FINGER GLUED JOINTS C2 — 55 TO C5 — 55

COMPRESSION TEST RESULT PARALLEL TO GRAIN

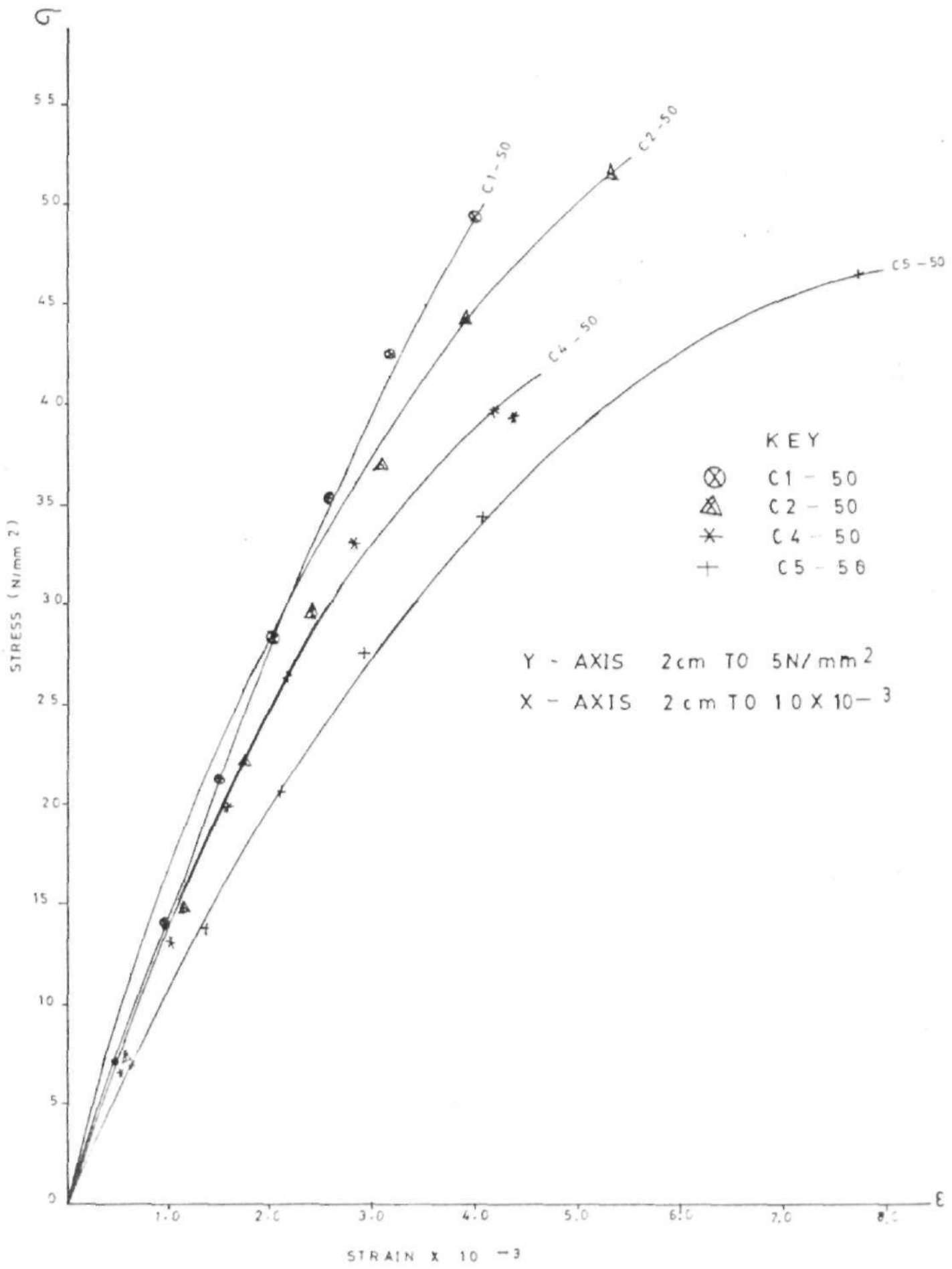
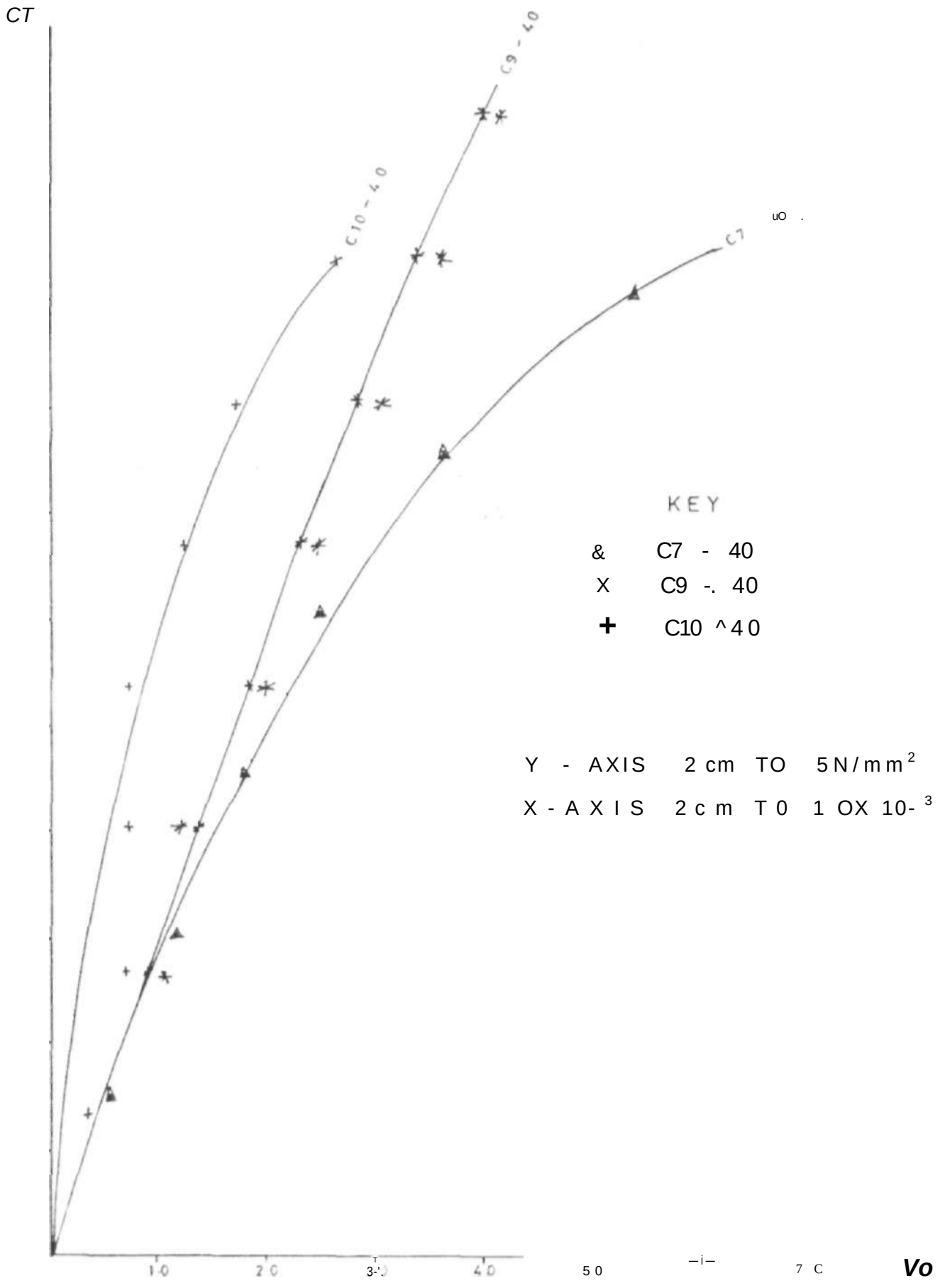
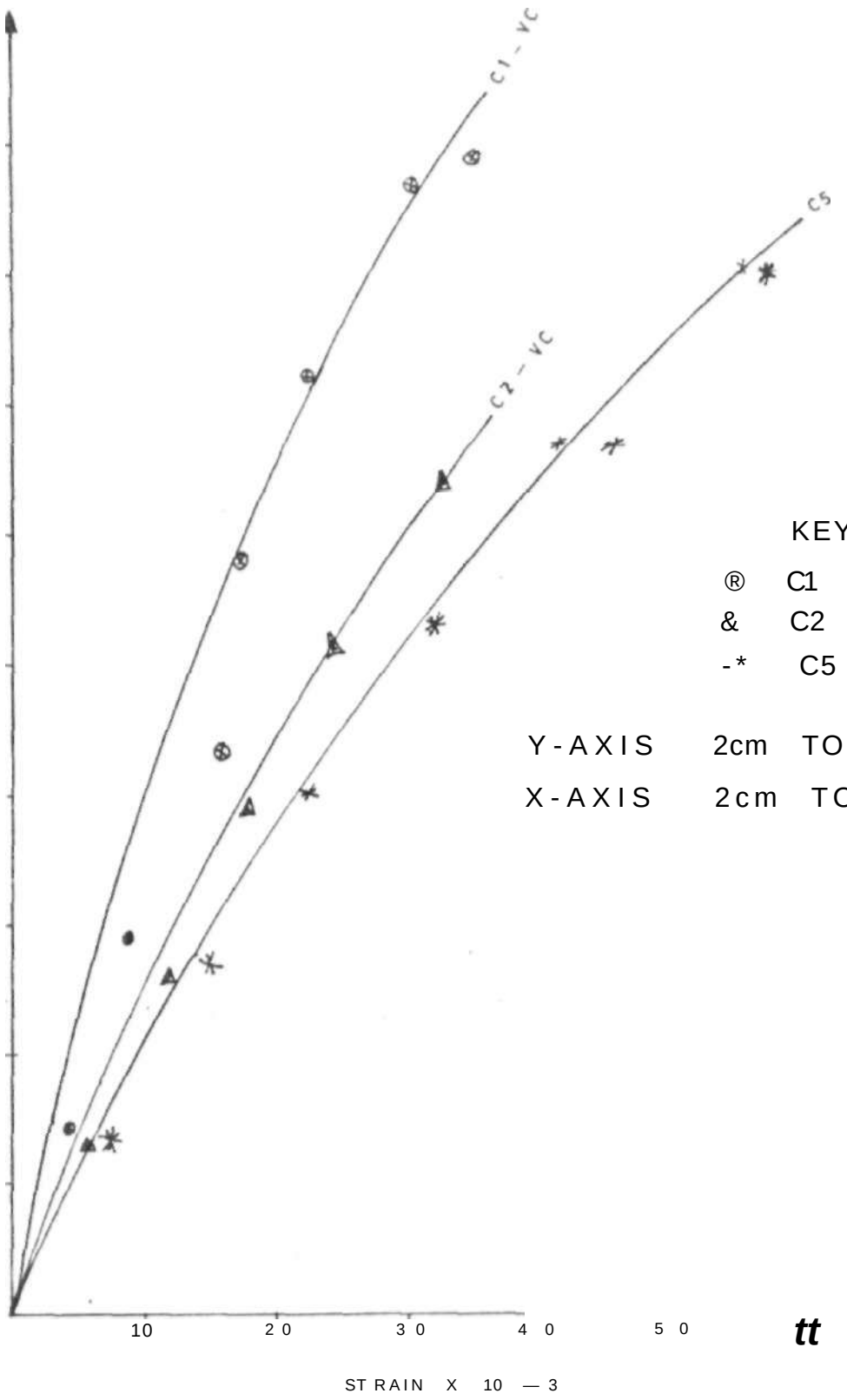


FIG: C-2 STRESS – STRAIN CURVES FOR TIMBER FINGER GLUED JOINTS C1 – 50 TO C5 – 50

COMPRESSION TEST RESULTS PARALLEL TO GRAIN



FIG'C-2> STRESS-STRAIN CURVES FOR TIMBER FINGER GLUED JOINTS C7 -4C TO C10 - 40



FI G-.C-4STRESS-STRAIN CURVES FOR TIMBER VERTICAL COMPONENT GLUEDJOINTS Cl-VC TO C5-VC (1 12)

u

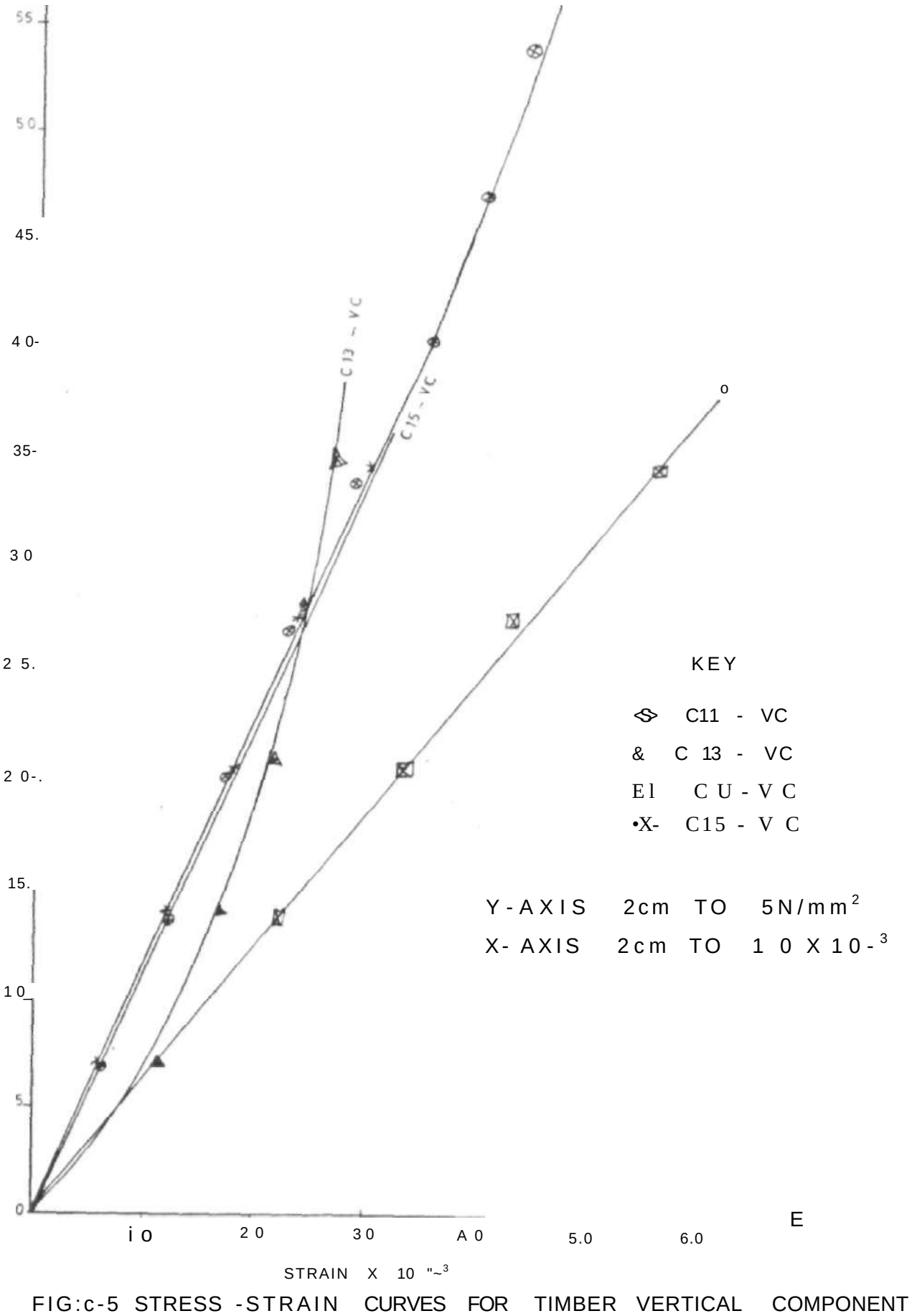


FIG:c-5 STRESS -STRAIN CURVES FOR TIMBER VERTICAL COMPONENT GLUED JOINTS C11-VC TO C15-VC (18)

COMPRESSION TEST RESULTS PARALLEL TO GRAIN

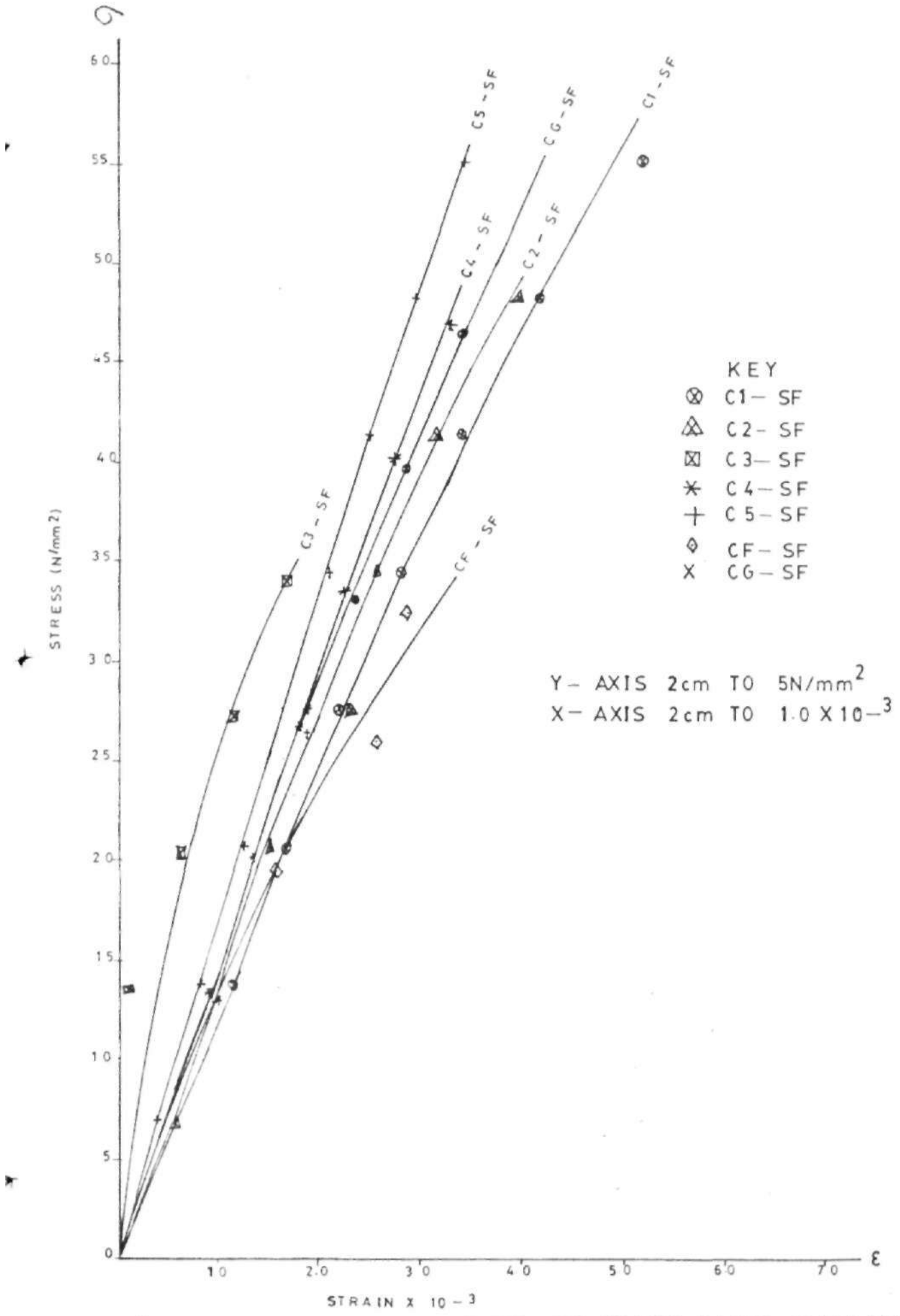
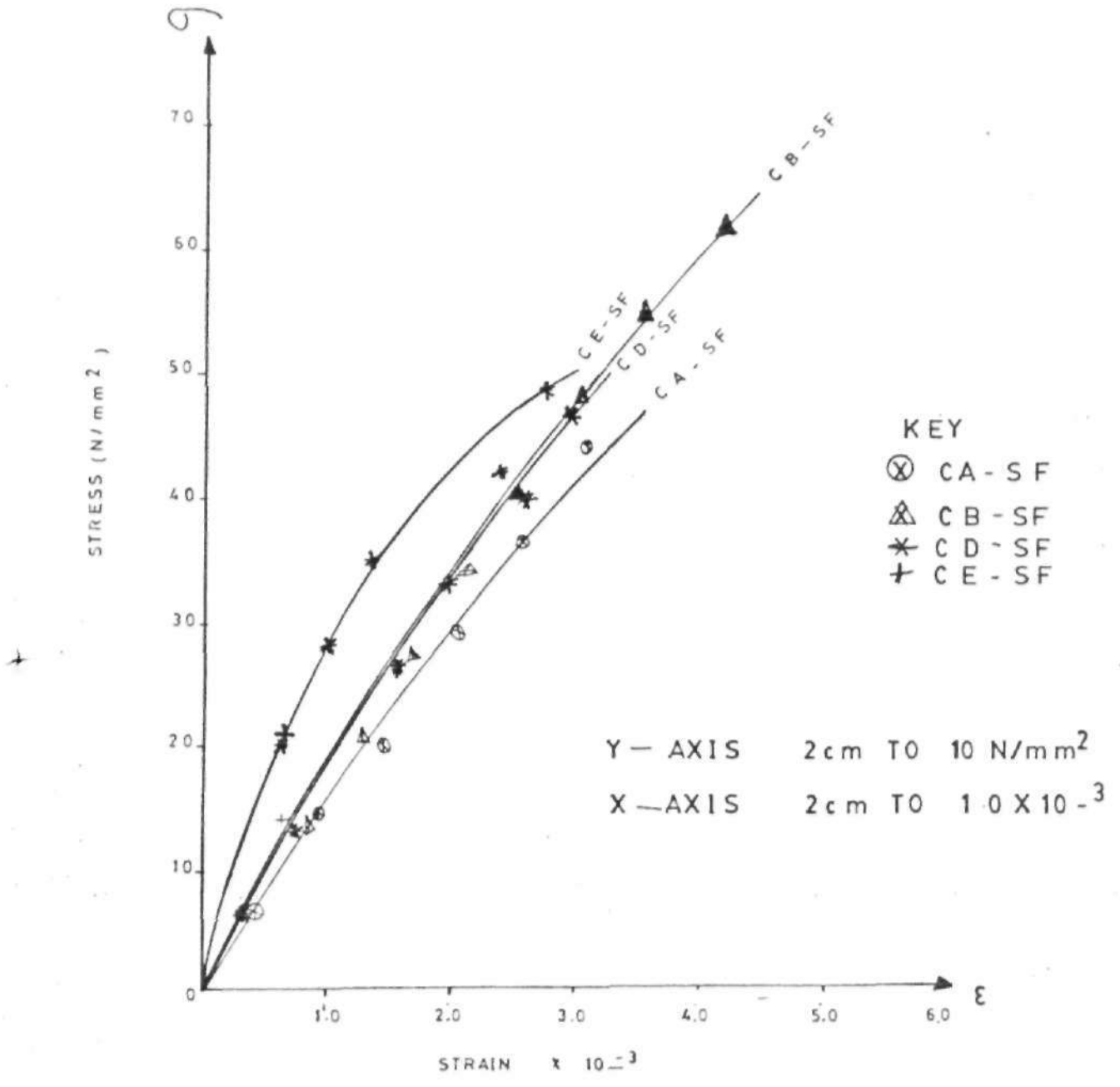


FIG:C-6 STRESS - STRAIN CURVES FOR TIMBER PLAIN SCARF GLUED JOINTS C1—SF TO C5 — SF / CG — SF (1:12)

COMPRESSION PARALLEL TO GRAIN RESULTS



FIGIC-7 STRESS-STRAIN CURVES FOR TIMBER PLAIN SCARF GLUED JOINTS CA-SF TO CE-SF (1:10)

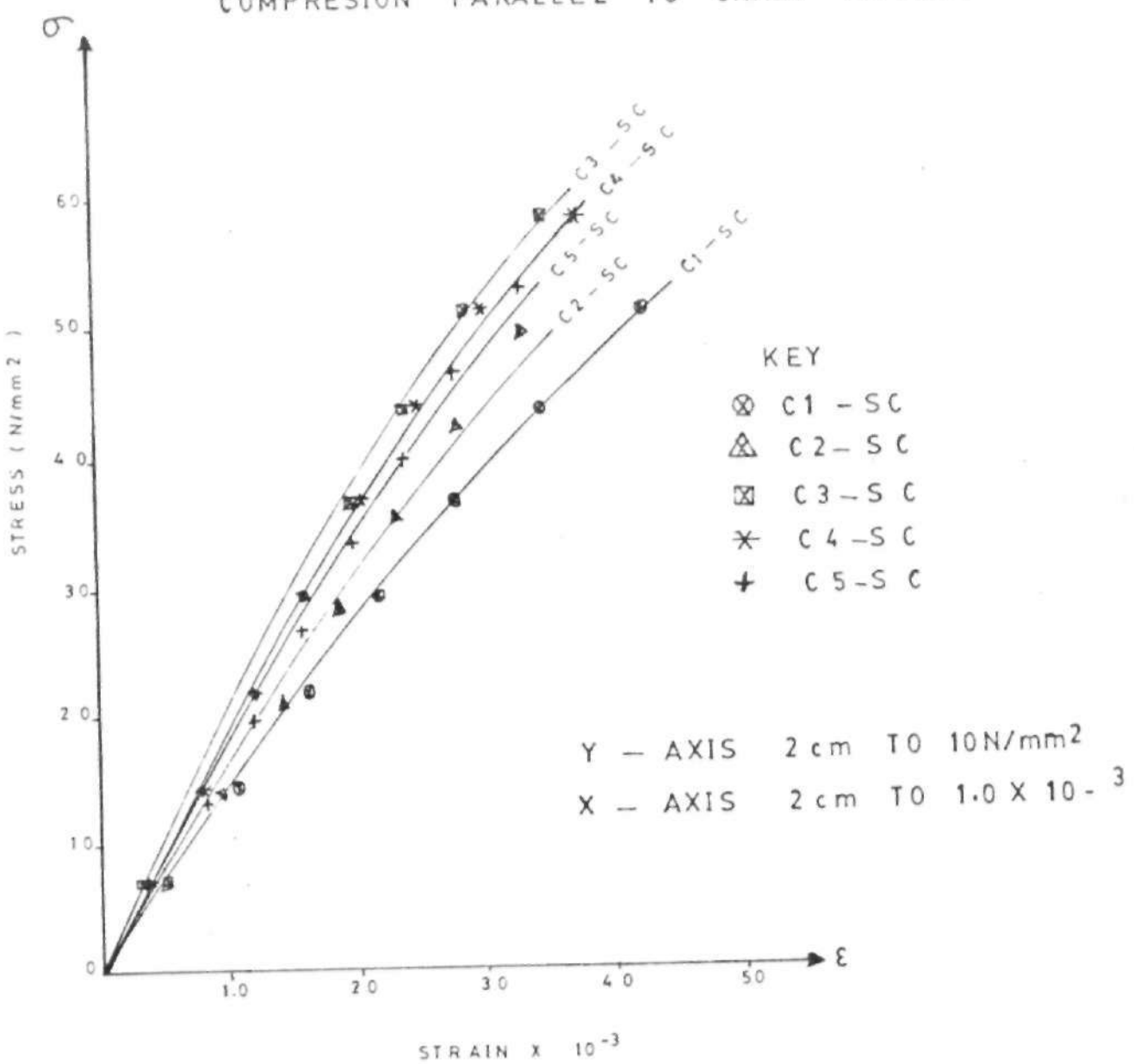


FIG:C-8 STRESS-STRAIN CURVES FOR TIMBER PLAIN SCARF GLUED JOINTS C1-SC TO C5-SC (1:8)

CONTROL SPECIMENS COMPRESSION PARALLEL TO GRAIN
RESULTS

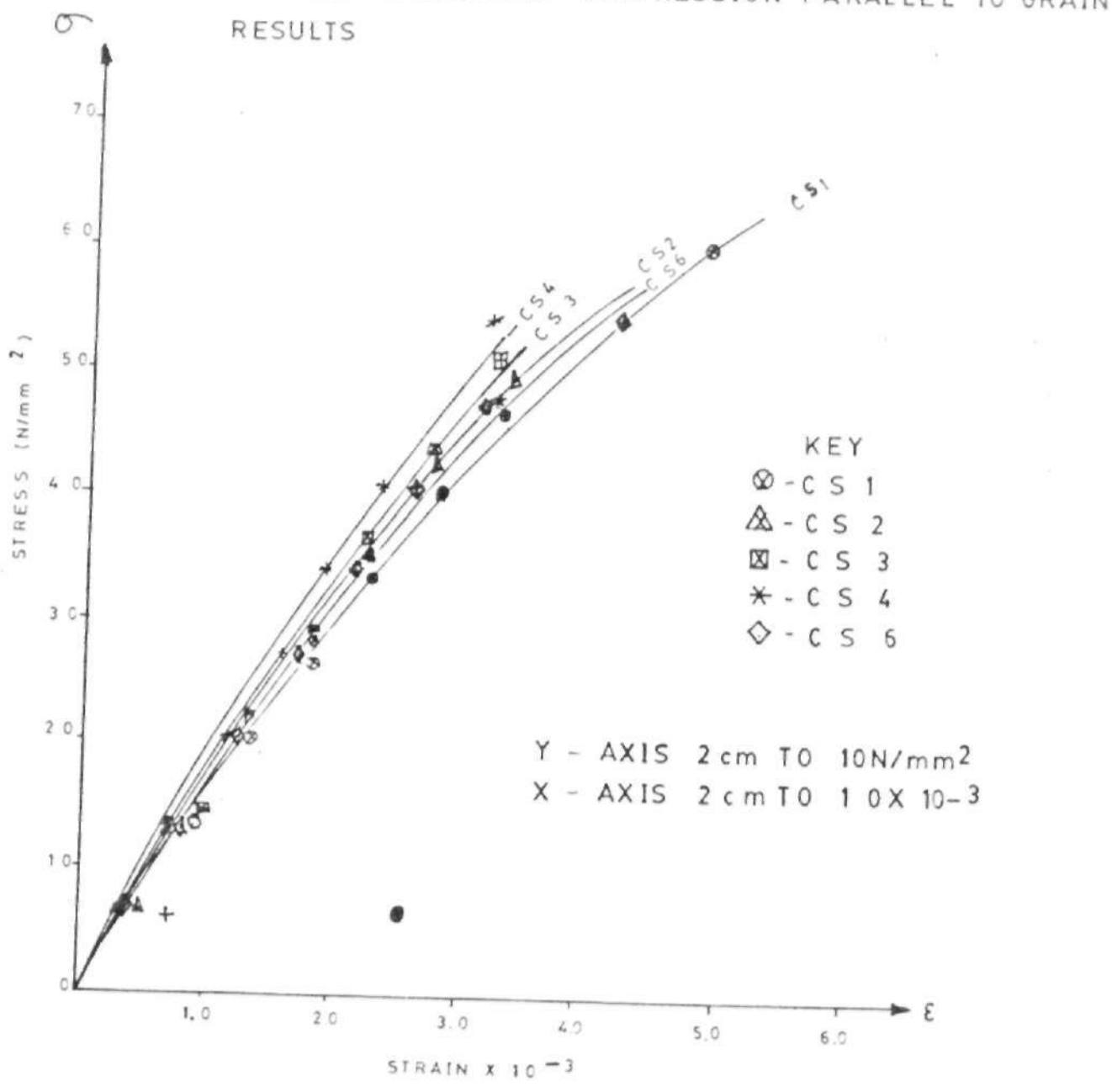


FIG:C-9 STRESS - STRAIN CURVES FOR TIMBER CONTROLLED SPECIMENS CS1 - CS6

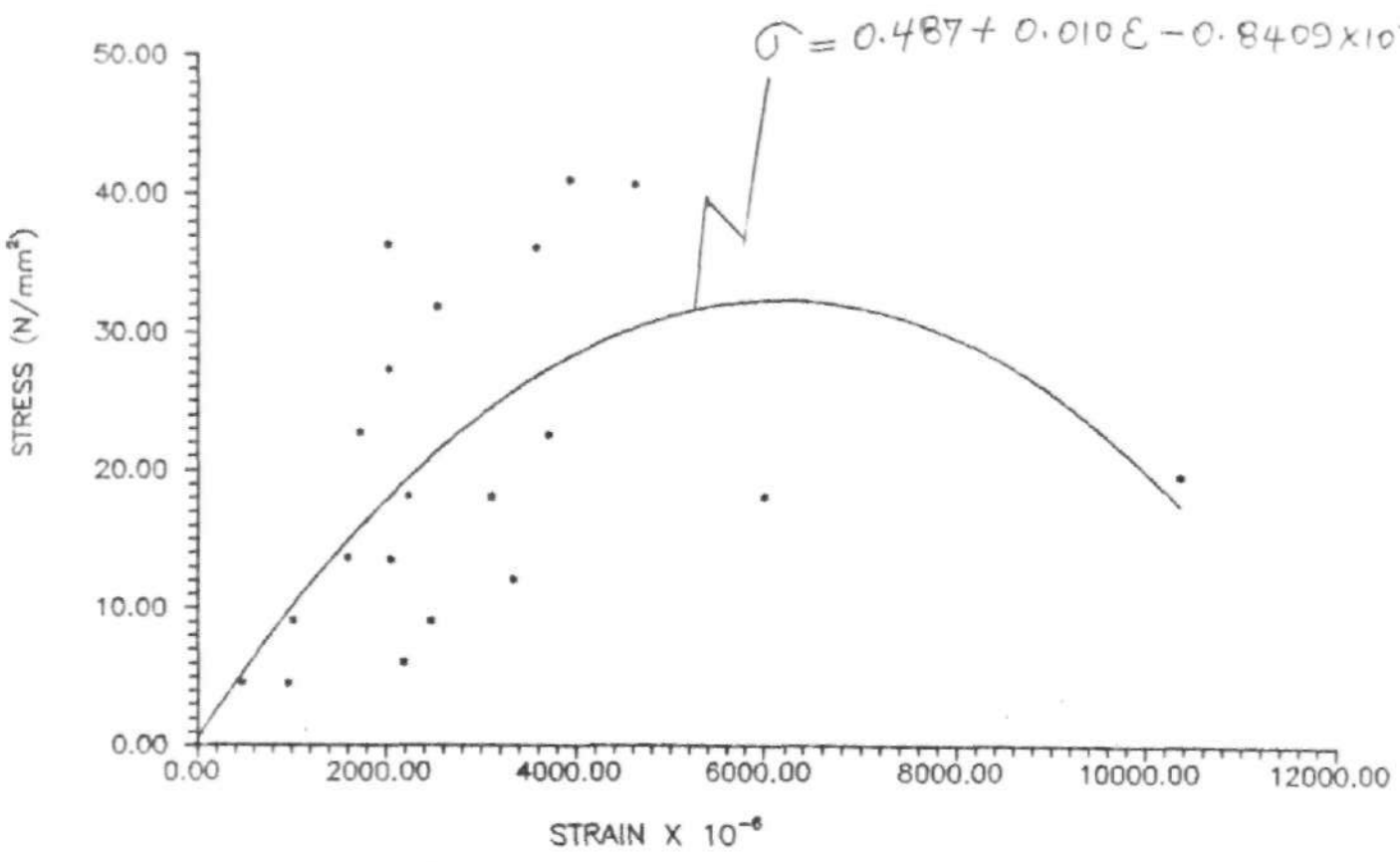


FIG. : (a) Flexural Test Parallel to Grains

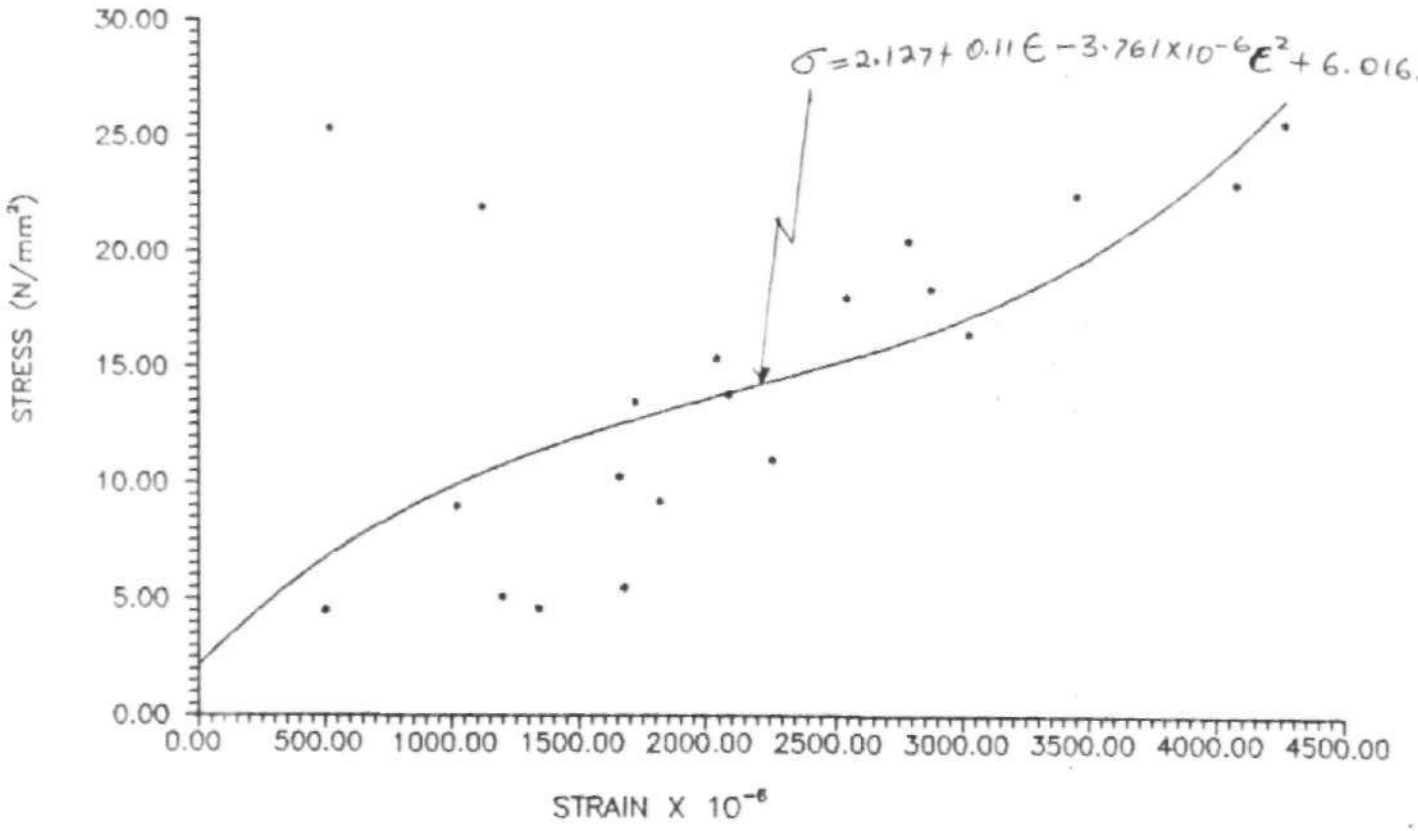


FIG. : (b) Flexural Test Parallel to Grains

150

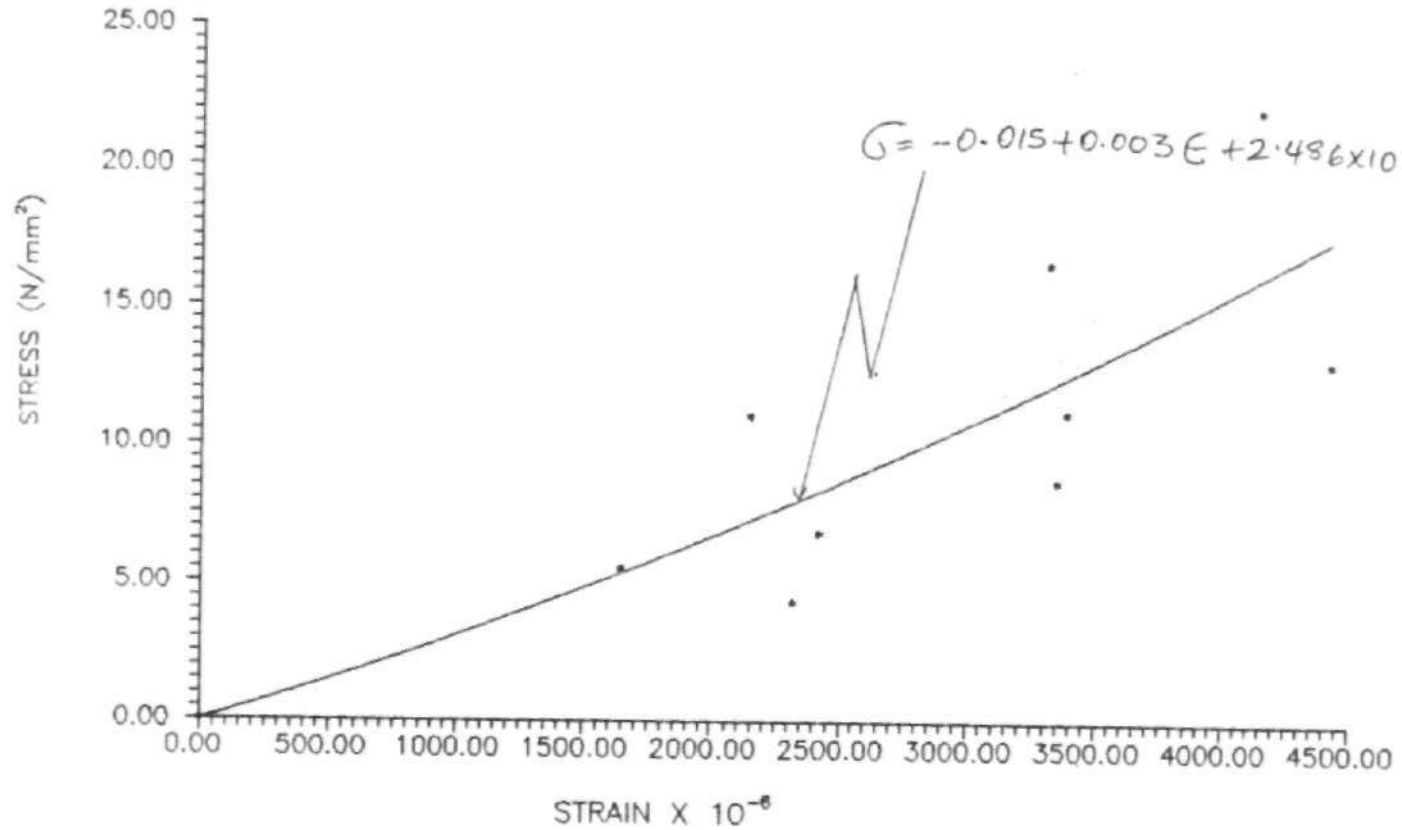


FIG. : (c) Flexural Test Parallel to Grains

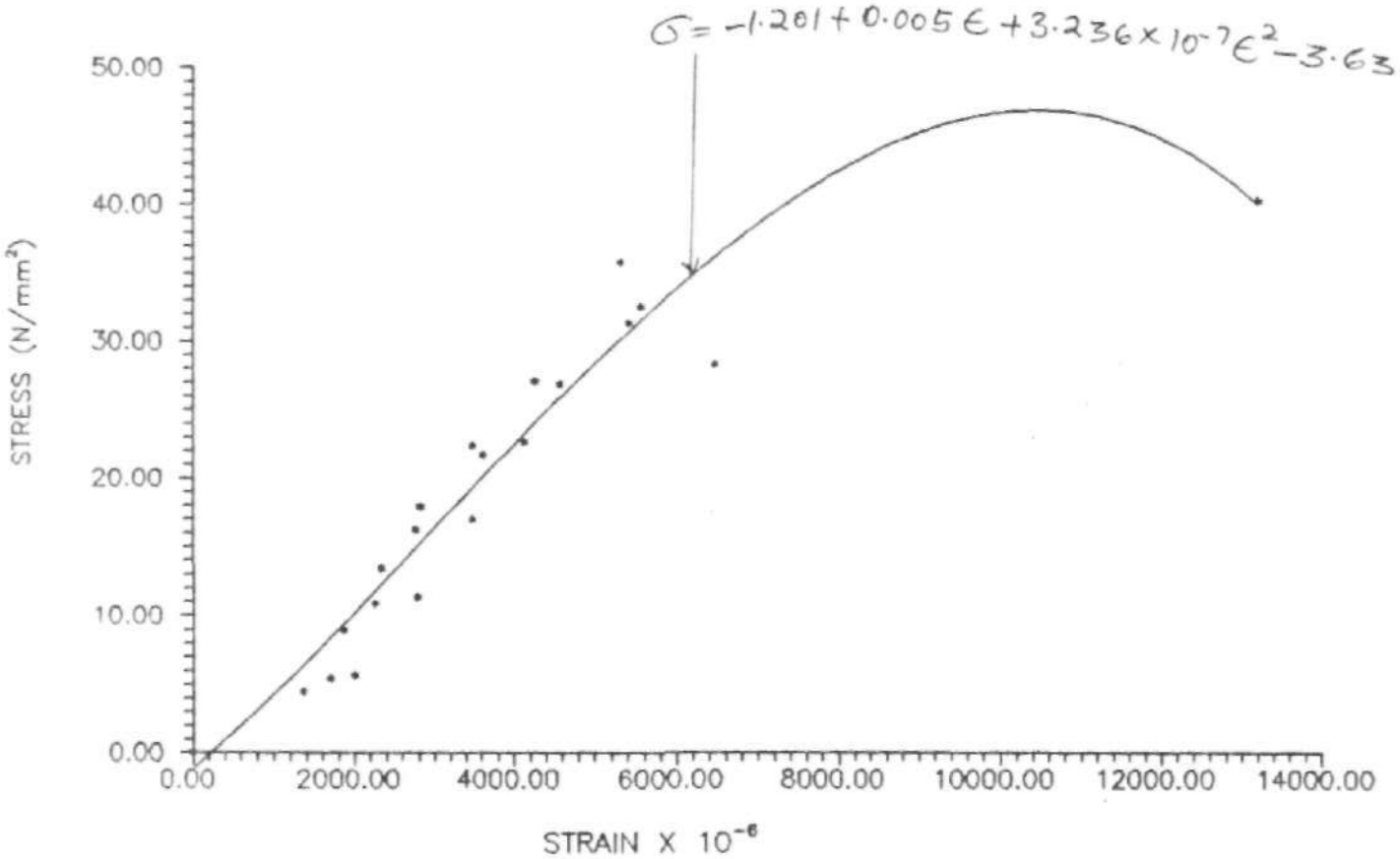


FIG. : (d) Flexural Test Parallel to Grains

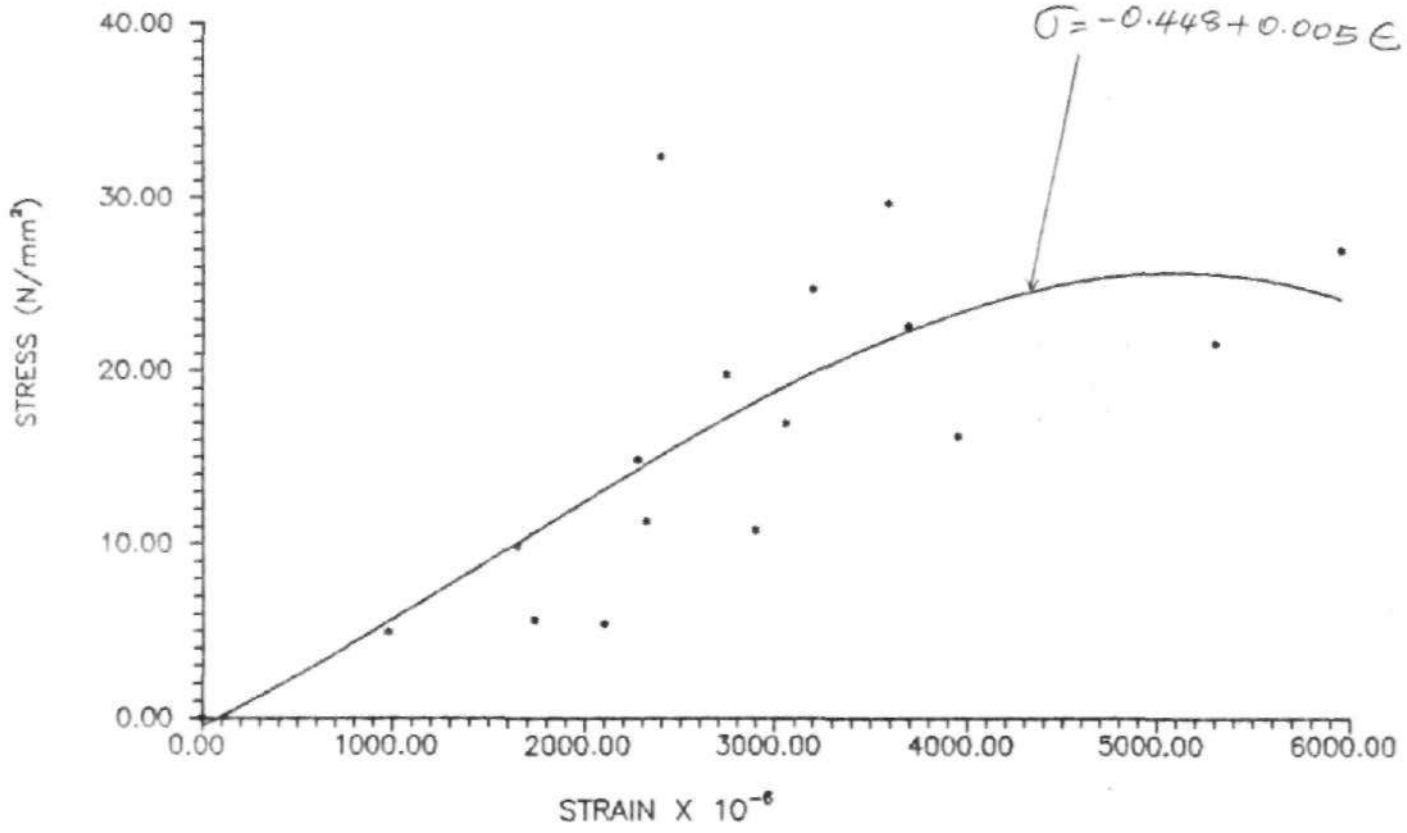


FIG. : (e) Flexural Test Parallel to Grains

$\sigma = 10.815 - 0.012\epsilon + 9.917 \times 10^{-6}\epsilon^2 - 1.549 \times 10^{-9}\epsilon^3$

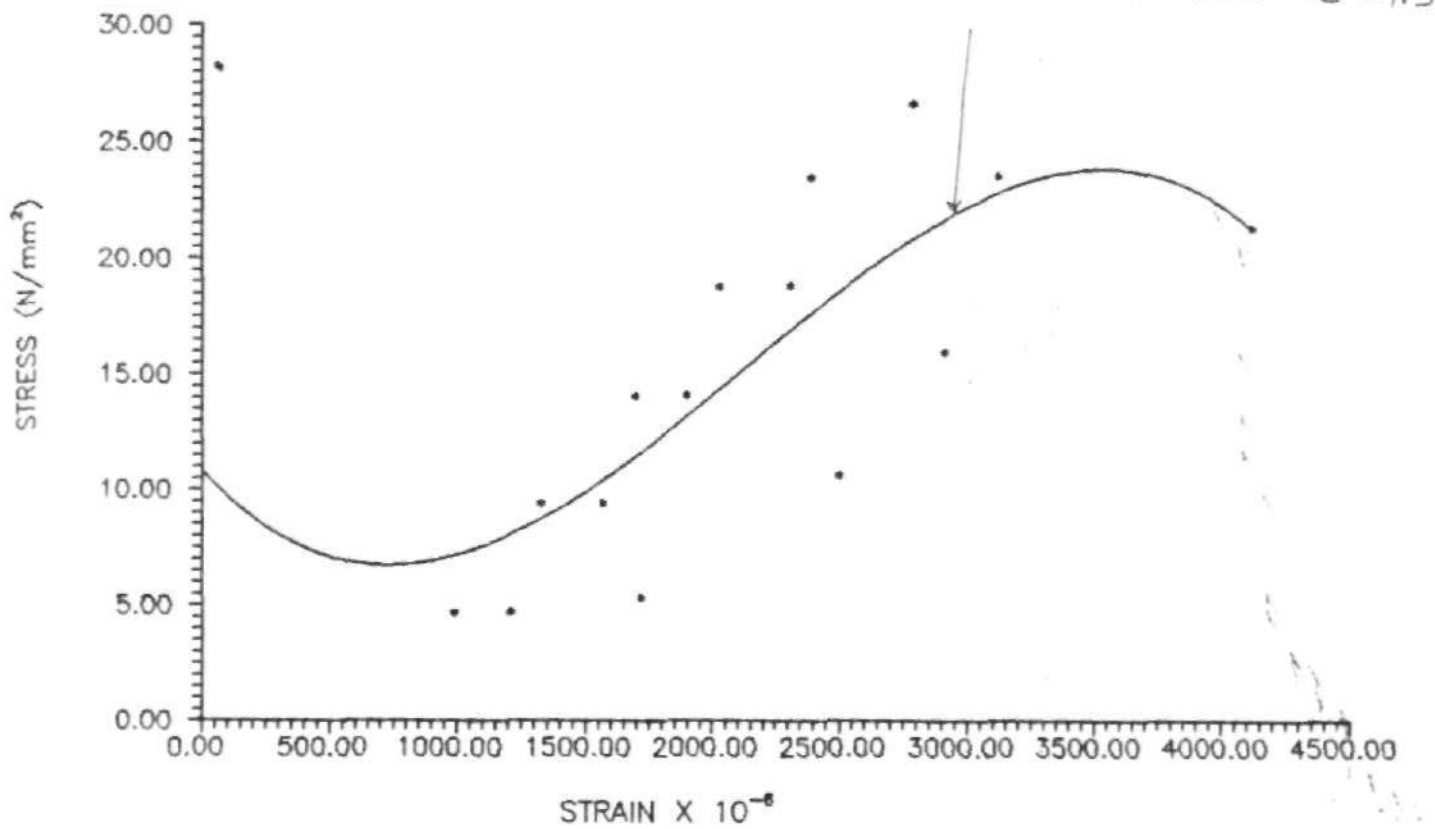


FIG. : (f) Flexural Test Parallel to Grains

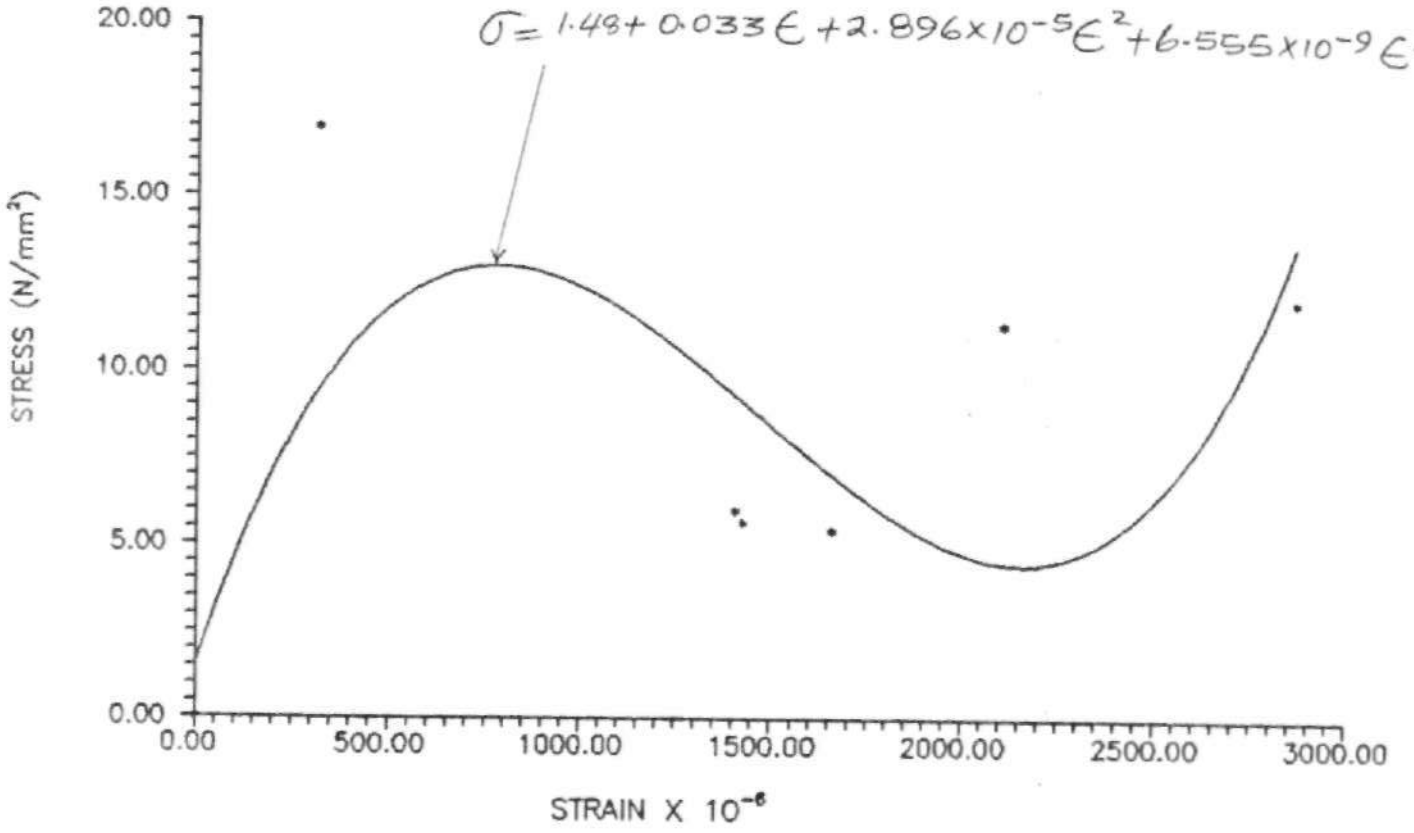


FIG. : (g) Flexural Test Parallel to Grains

$\sigma = 4.756 + 0.001\varepsilon + 2.264 \times 10^{-6}\varepsilon^2 - 2.821 \times 10^{-10}\varepsilon^3$

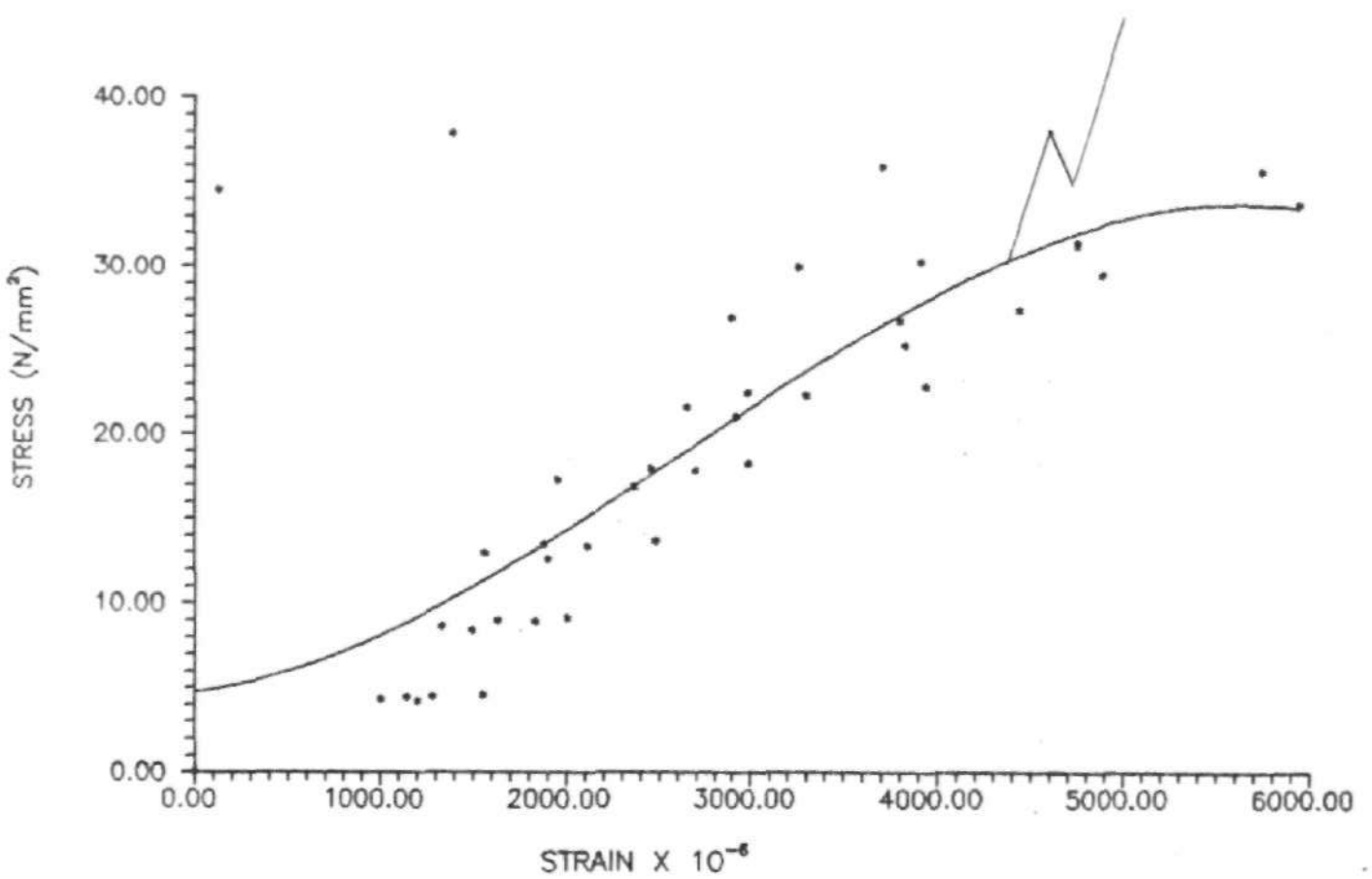


FIG. : (h) Flexural Test Parallel to Grains
(Control specimens)

$\sigma = 2{\cdot}232 + 0{\cdot}010\varepsilon - 3{\cdot}630\times10^{-6}\varepsilon^2$

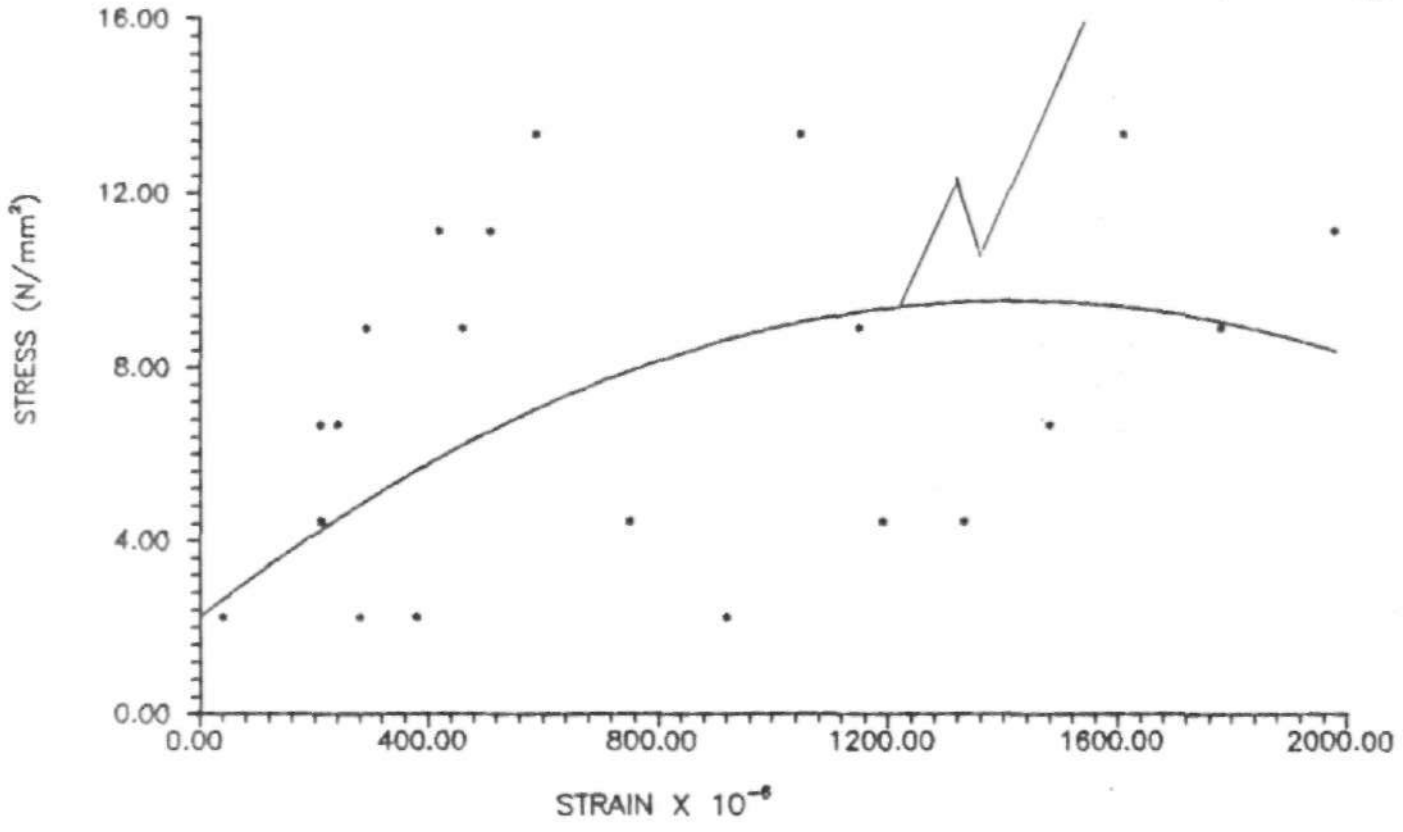


FIG.: (a) Tension Test Parallel to Grains

$\sigma = 0.557 + 0.017\varepsilon - 1.251 \times 10^{-6}\varepsilon^2$

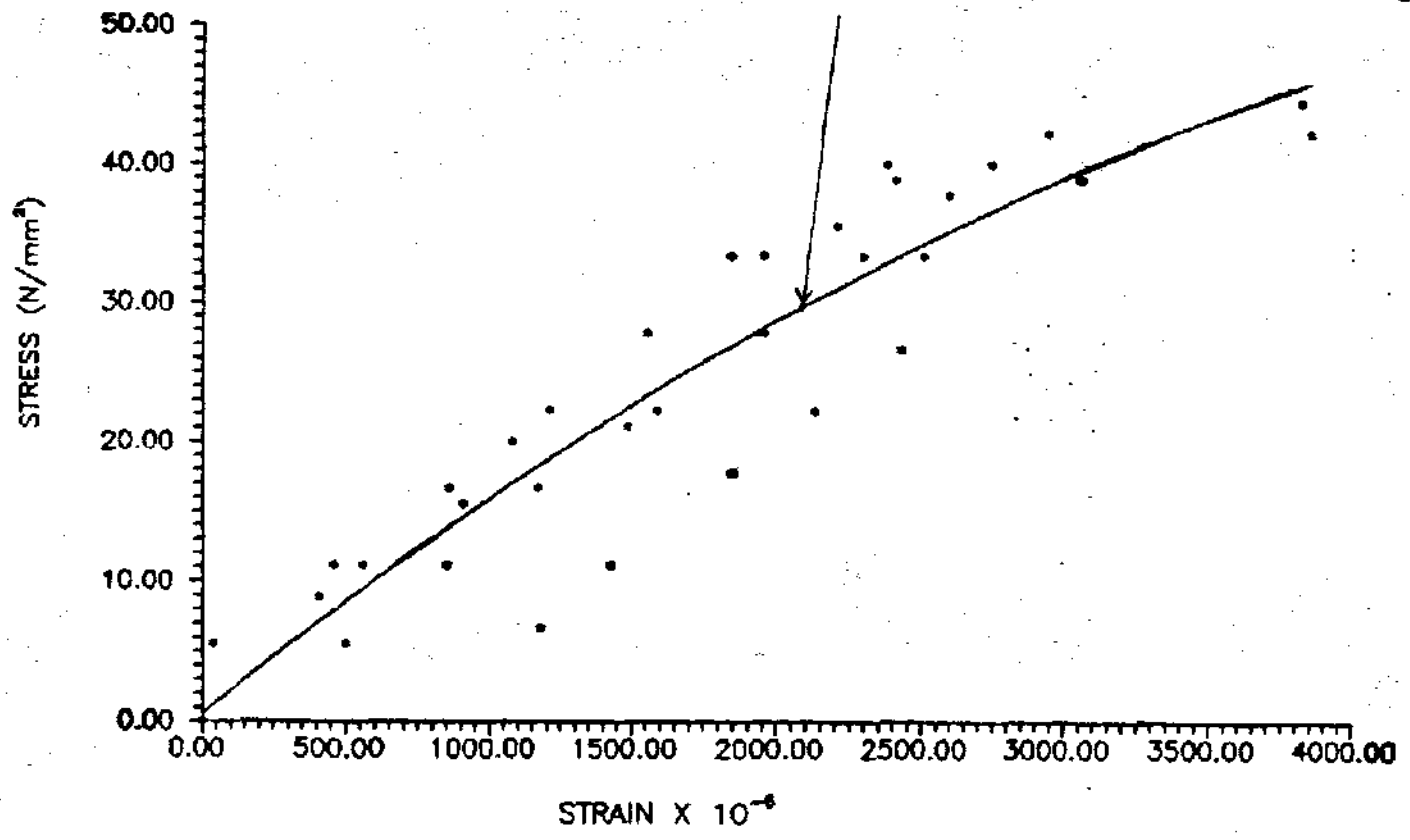


FIG.: (b) Tension Test Parallel to Grains

(Control Specimens)

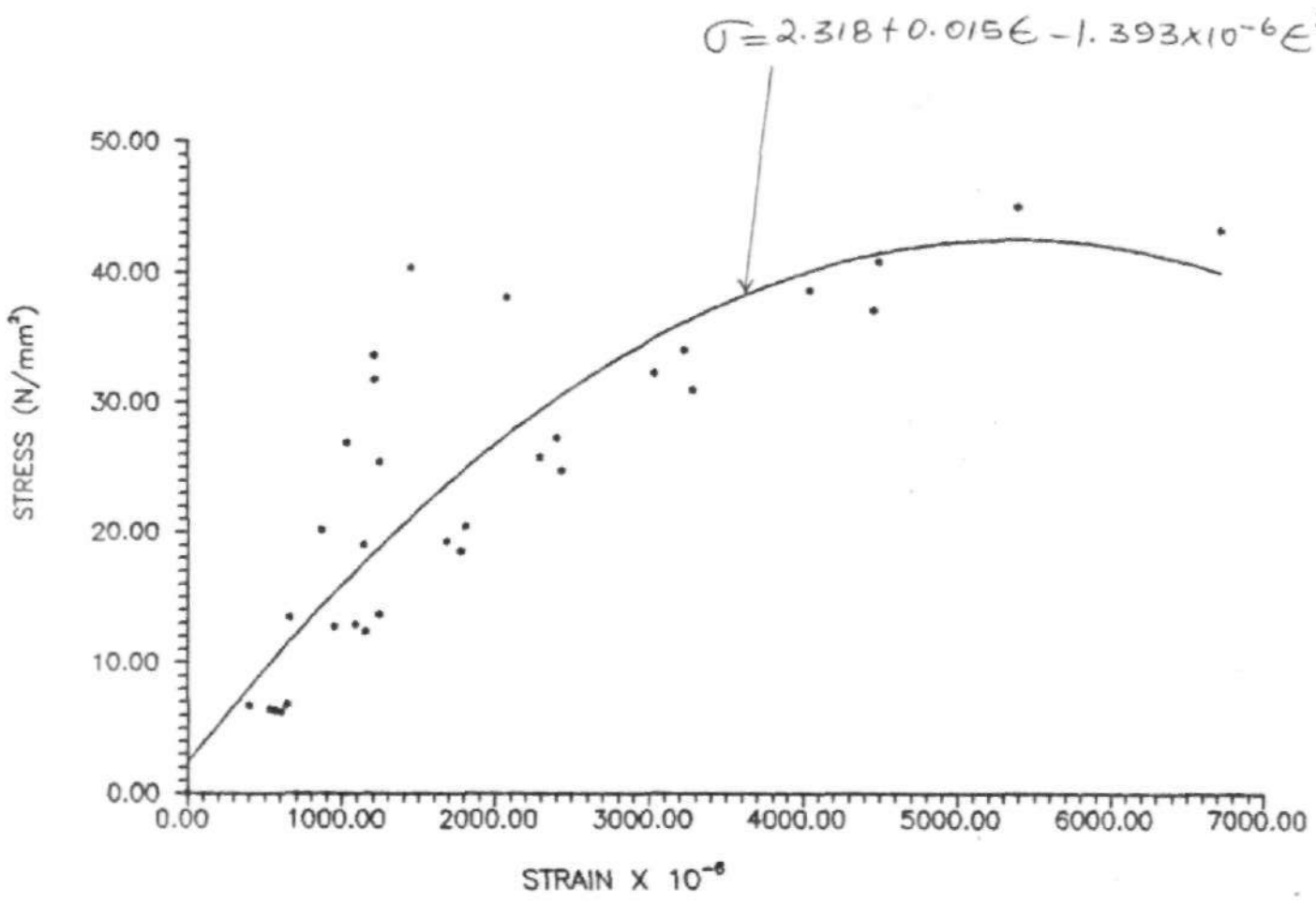


FIG. : (a) Compression Test Parallel to Grains

$\sigma = 5.334 + 0.012\epsilon - 0.7822 \times 10^{-6}\epsilon^2$

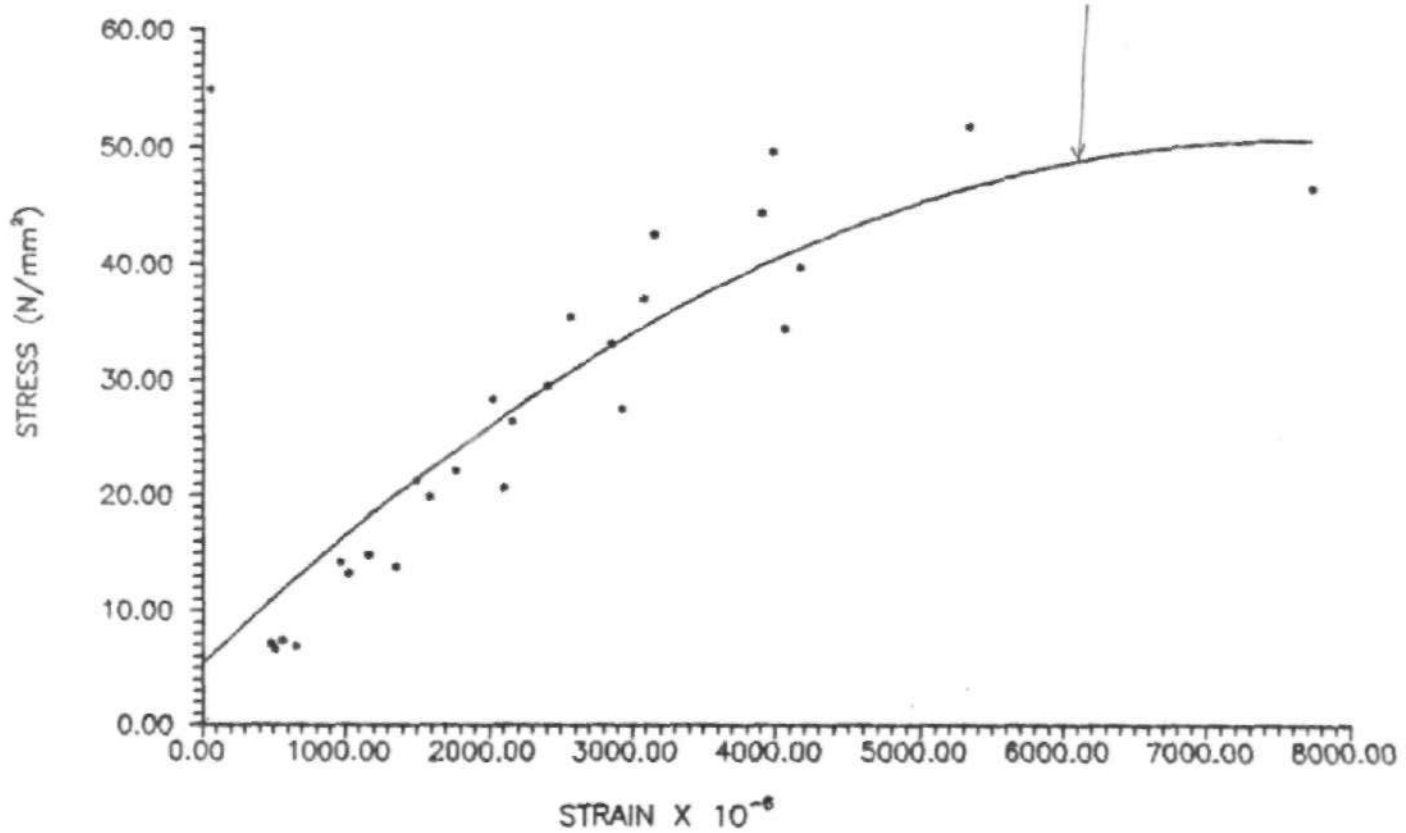


FIG. : (b) Compression Test Parallel to Grains

160

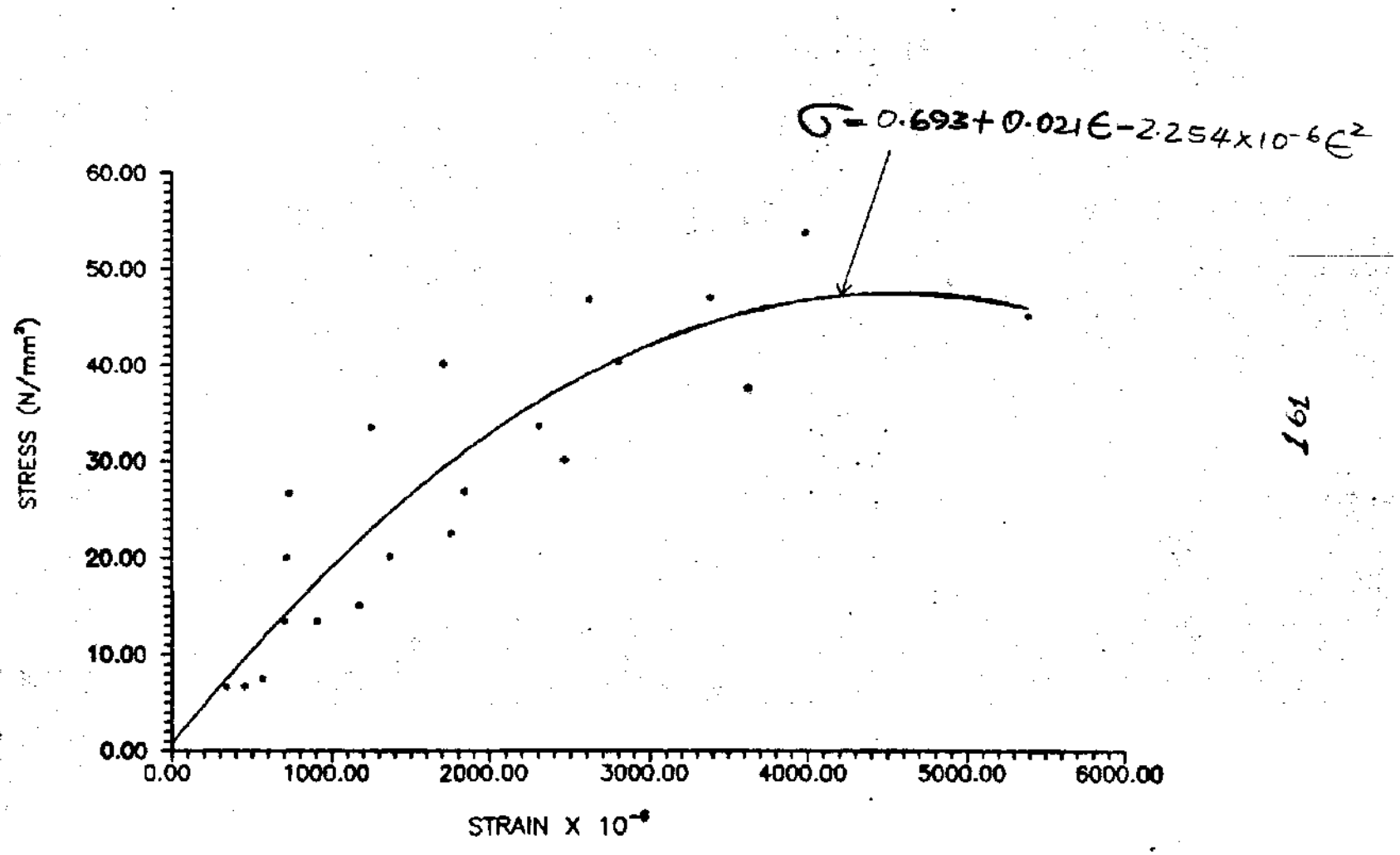


FIG. : (c) Compression Test Parallel to Grains

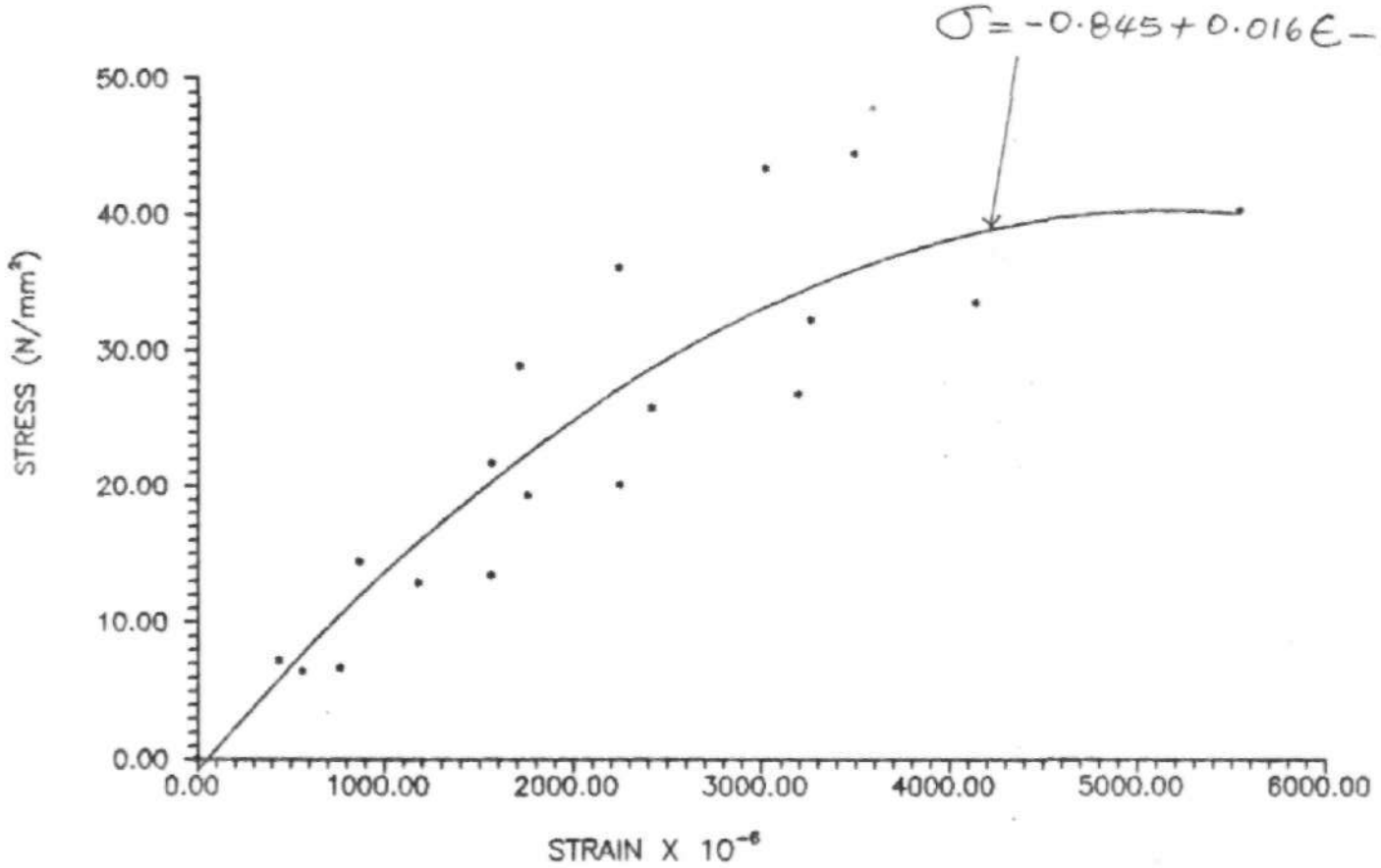


FIG. : (d) Compression Test Parallel to Grains

162

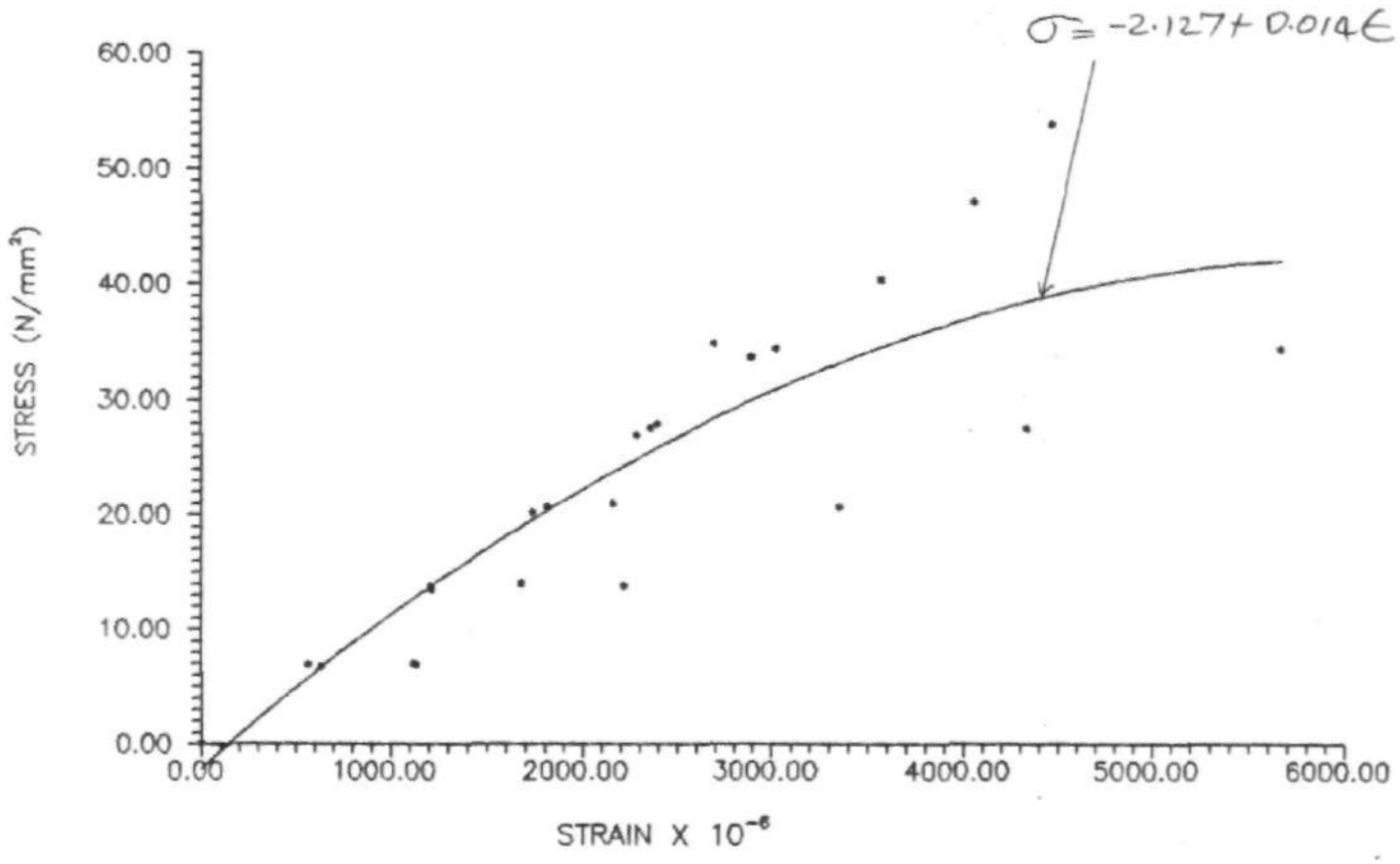


FIG. : (e) Compression Test Parallel to Grains

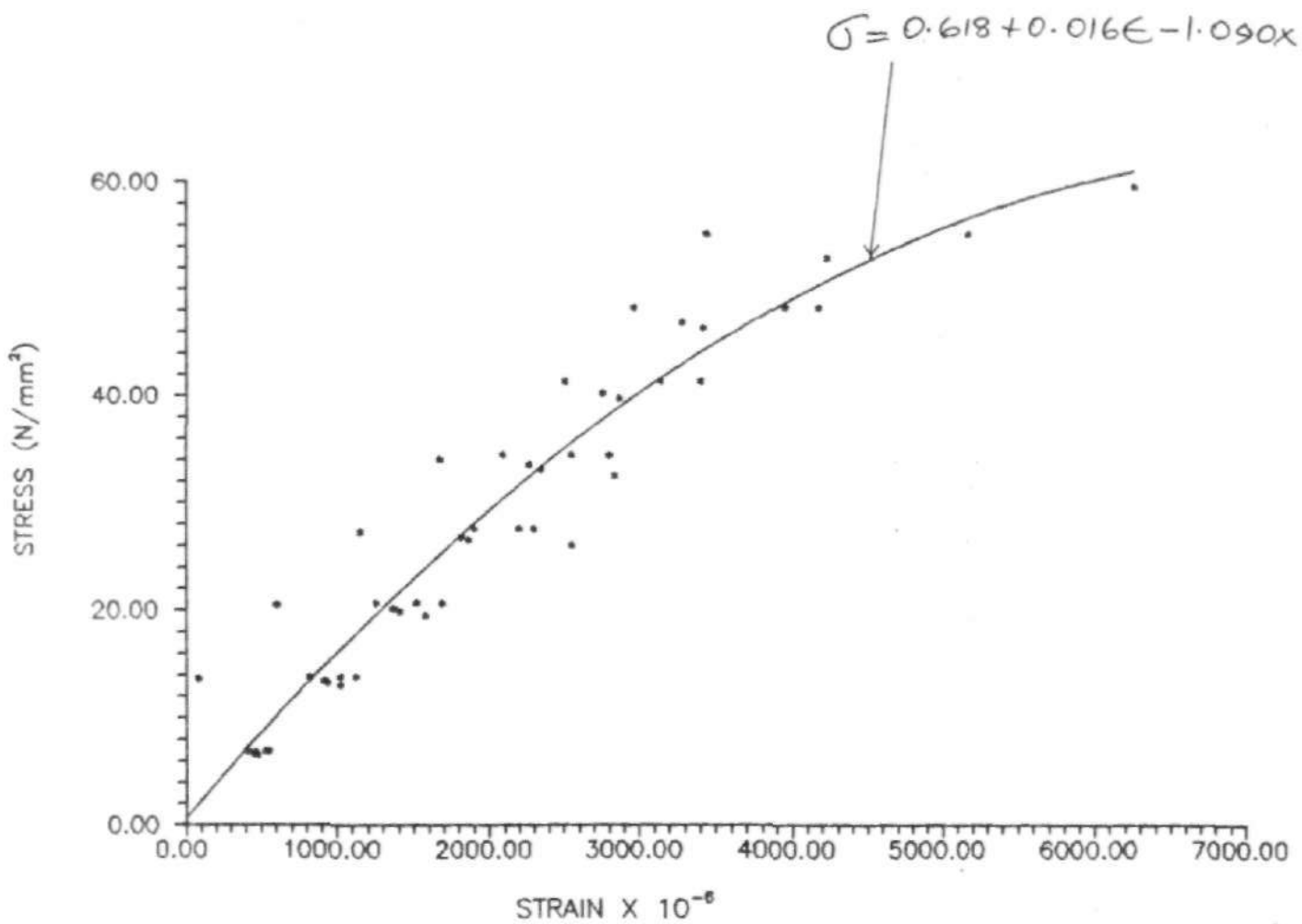


FIG. : (f) Compression Test Parallel to Grains

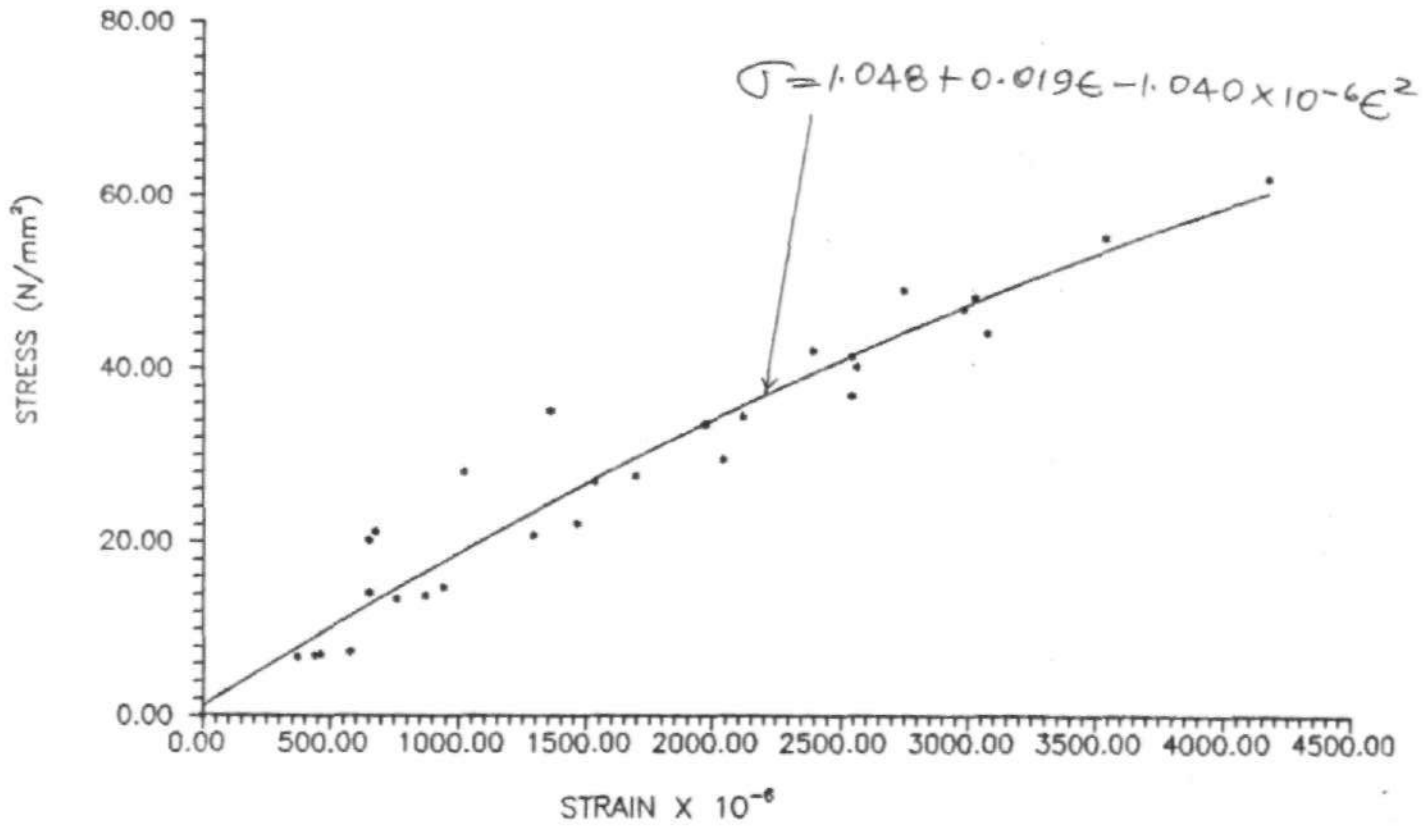


FIG. : (g) Compression Test Parallel to Grains

$\sigma = 0.997 + 0.020\varepsilon - 1.346 \times 10^{-6}\varepsilon^2$

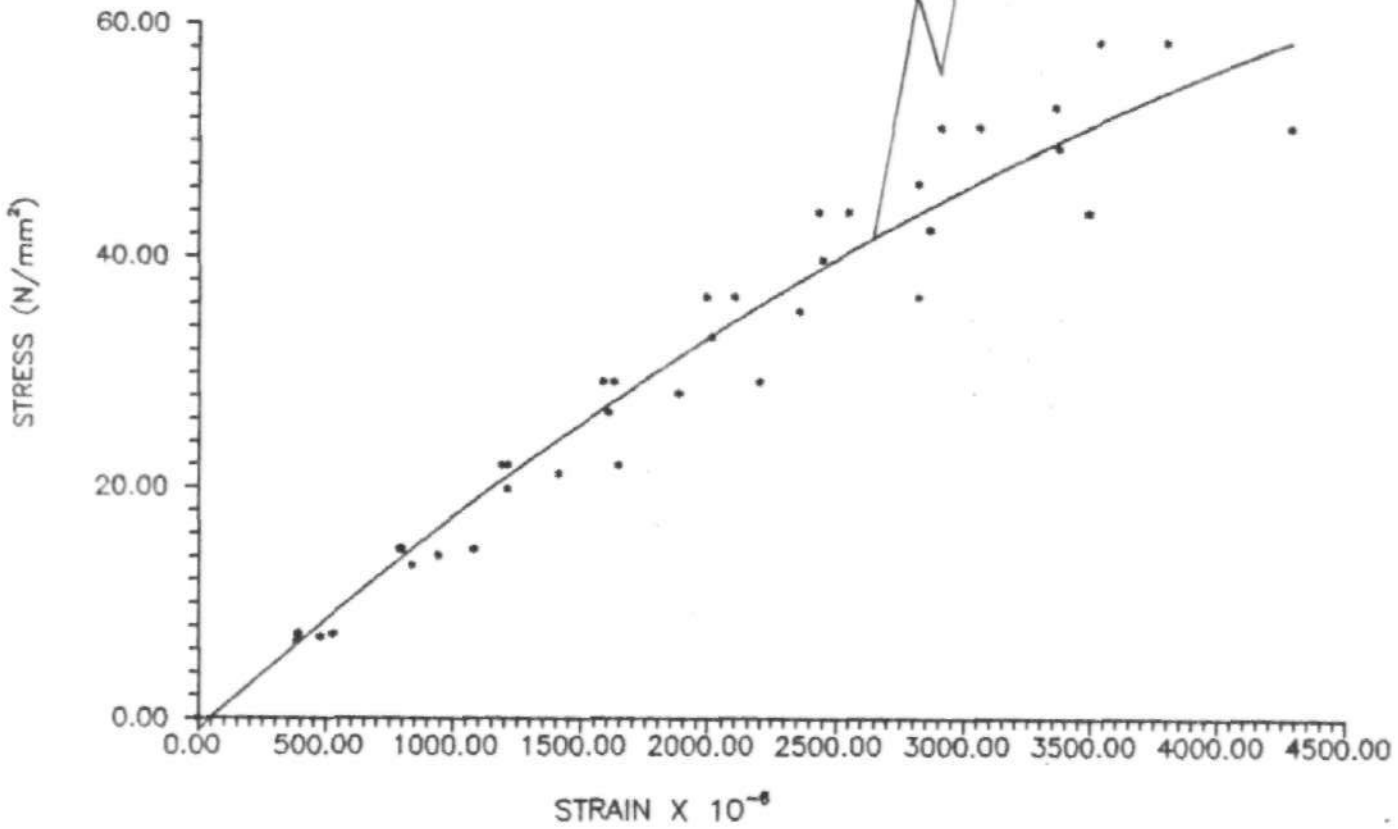


FIG. : (h) Compression Test Parallel to Grains

$\sigma = -0.382 + 0.018\varepsilon - 0.9761 \times 10^{-6}\varepsilon^2$

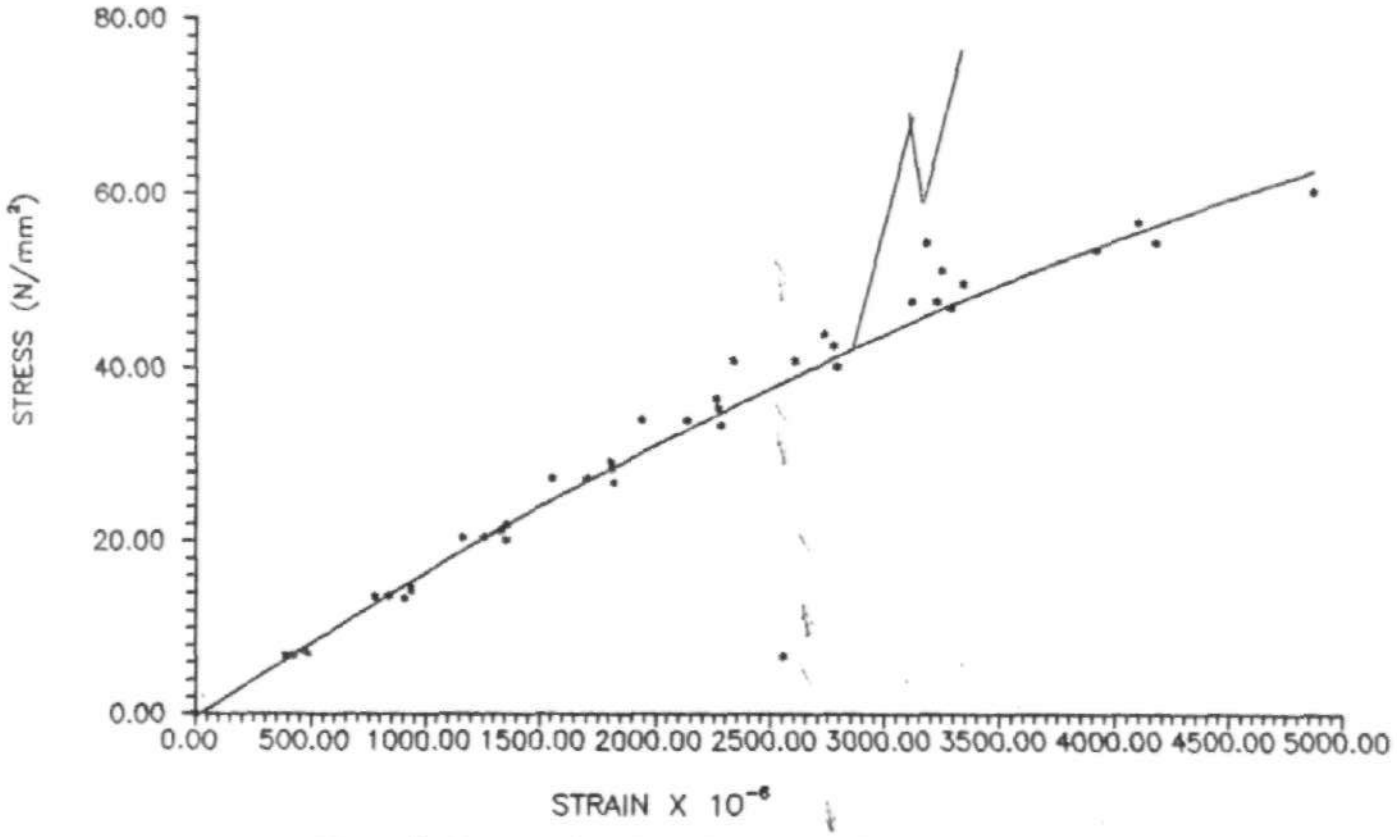


FIG. : (i) Compression Test Parallel to Grains

(Control specimens)

APPENDIX 3: FORMULAE AND SAMPLES CALCULATIONS

FORMULAE[4,6 and 9].

1. Moisture Content/Density Determination

(a) $x = \frac{W_1 - W_0}{W_0} \times 100$

(b) $D = \frac{W_1}{V_1} = \frac{W_1}{Lxbxh}$

(c) E.R. = $\frac{\text{Moisture Content/Density of Joint piece}}{\text{Moisture Content/Density of controlled piece}} \times 100\%$

where:-

W_1 = Weight of sample at test in grammes.

W_0 = Weight of oven-dry Timber sample, at 103 ± 2°C, in grammes.

V_1 = Volume of Timber sample at test.

L = Length of sample, in millimetres

b = Breadth of sample, in millimetres.

h = Height of sample, in millimetres.

X = Percentage of moisture content.

D = Density.

2. Static Bending (flexural) Test

(a) F.S at L.P. = $\frac{3P^1a}{bh^2}$ (Read from the graph)

(b) F.S. at M.L. (or M.O.R.) = $\frac{3Pa}{bh^2}$ (BS 373: 1957; a = L/6)

$F_j = F_{max} L/bh^2$ (BS 5291: 1984; a = L/3)

(c) $E_B = \frac{\sigma \text{ L.P.}}{E \text{ L.P.}}$ (Read from the stress - strain slope of the graph at L.P).

(d) $fb = \frac{MMax}{Z} = \frac{6\ Mmax}{bd^2} = MOR$ (F.S. at M.L.)

(e) E.R. = $\frac{\text{F.S. at M.L. (MOR) of jointed piece}}{\text{F.S. at M.L. (MOR) of controlled piece}} \times 100\%$

where:-

P^l = Load in Newton at Limit of Proportionality

a = distance in millimetre between point of application of Load and support (L/6)

b = Breadth (or width) in millimetres

h = Depth in millimetre

Fmax = Recorded maximum load in Newton

P = Maximum Load in Newton

L = The test span in millimetres

σL.P.= Stress at limit of proportionality in Newton per millimetre square

ϵ.L.P. = Strain value at limit of proportionality

Mmax = Maximum moment (in KNm x 10^6 Nmm)

F.S. at L.P. = Fibre stress in Newton per square millimetre at limit of proportionality

F.S. at M.L. = Equivalent fibre stress in Newton per square millimetre at maximum load.

M.O.R. = modulus of Rupture in Newton per square millimetre.

f_j = modulus of Elasticity in Newton per square

millimetre.

E_B = modulus of Elasticity in Newton per square millimetre.

fb = Bending stress in Newton per square millimetre.

F.S. at L.P. and E_B are obtained from the stress-strain curves.

3. Compression Test Parallel to Grain

(a) fcpar = C.S. at M.L. = P/A

(b) C.S. at L.P. = P^1/A

(c) $E_c = \frac{\sigma_c}{\epsilon_c}$

(d) E.R. = $\frac{\text{C.S. at M.L. of jointed piece}}{\text{C.S. at M.L. of controlled piece}} \times 100\%$

where:-

P = Maximum crushing load in Newton.

A = Cross-sectional area in square millimetre

P^1 = Load in Newton at Limit of Proportionality

σ_c = Stress at limit of proportionality.

ϵ_c = Strain at limit of proportionality.

fcpar = Compressive stress at maximum load (C.S. at M.L.).

C.S. at L.P. = Compressive stress at limit of proportionality.

E_c = modulus of elasticity.

4. Tensile Test Parallel to Grain

(a) T.S. at M.L. = P/A

(b) T.S. at L.P. = P^{l}/A

(c) $E_{T} = \frac{\sigma_{T}}{\epsilon_{T}}$

(d) E.R. = $\frac{\text{T.S. at M.L. of jointed piece}}{\text{T.S. at M.L. of Controlled piece}} \times 100\%$

where:-

P = Maximum load in Newton.

P^{l} = Load in Newton at Limit of Proportionality

σ_{T} = Tensile stress at limit of Proportionality.

ϵ_{T} = Strain at limit of proportionality.

T.S. at M.L. = Tensile stress at maximum load.

T.S. at L.P. = Tensile stress at limit of proportionality.

E_{T} = Young modulus or modulus of elasticity.

1. Moisture Content/Density Determination

Sample piece mark FB3 from Table 4.4:

Moisture content determination of Bending test samples.

W_{1} = 36.0g

W_{0} = 32.0g

L = 50.0mm

b = 30.0mm

h = 30.0mm

D of clear specimen = 792.25kg/m

M.C. of clear specimen = 13.93%

E.R.D. = (798.28/792.25) x 100% = 100.8%

E.R.M.C. = (13.01/13.93) x 100% = 93.4%

$$X = \frac{36.0 - 32.0}{32.0} \times 100 = 12.5\%$$

$$D = \frac{0.036}{0.50 \times 0.03 \times 0.03} = 800 Kg/m^3$$

From Table 4.1, FB3.

W_1 = 4,199g

L = 756mm

b = 50mm

h = 144mm

$$D = \frac{4.199}{0.756 \times 0.05 \times 0.144} = 771.42 Kg/m^3$$

$$\sim 800 Kg/m^3$$

2. Static Bending Test

For test piece mark FB3 from Table 4.1

P = 180,000N

P^1 = 22,000N

L = 468mm

a = 78mm

b = 50mm

h = 144mm

$\sigma L.P = 4 N/mm^2$ (from Graph)

$\epsilon L.P = 0.9 \times 10^{-3}$ (from Graph).

Δ = 2.4mm (from graph)

Mmax = 7.02×10^{6}Nmm (calculated)

W_1 = 4,199g

N = P+ql = 180,000N

F.S. at M.L. of clear specimens = $35.64 N/mm^2$

F.S. at M.L. of FB3 Group = $33.70 N/mm^2$

(a). F.S. at L.P. = σL.P. = $4.0 N/mm^2$ (from Graph)

(b) F.S. at M.L. (M.O.R.) = $\frac{3 \times 180 \times 10^{3} \times 78}{50 \times 144^2} = 40.63 N/mm^2$

(c) $E_B = \frac{4 N/mm^2}{0.9 \times 10^{-3}} = 4,444.44 N/mm^2$

(d) fb = $\frac{6 \times 7.02 \times 10^{-6}}{50 \times 144^2} = 40.63 N/mm^2$

fb = F.S. at M.L. = M.O.R.

(e) E.R. of FB3 Group = (33.70/35.64) x 100% = 94.6%

3. Compression test parallel to grain: For Test piece mark C3-55, from Table 4.2.

P = 140,000N

A = $84 \times 37 = 3108 mm^2$

$\sigma_c = 9.2 N/mm^2$

$\epsilon_c = 0.65 \times 10^{3}$

C.S. at M.L., f_c of clear specimens = $60.66 N/mm^2$

C.S. at M.L. of C3-55 Group, $f_c = 45.27 N/mm^2$

(a) C.S. at M.L., fc = $\frac{140,000N}{3108 mm^2} = 45.05/mm^2$

(b) C.S. at L.P., $fc_{LP} = \sigma C = 9.2N/mm^2$ (from Graph)

(c) $Ec = \frac{7.0x10^3}{0.5} = 14,000N/mm^2$ (slope of stress-strain curve)

(d) E.R. of C3-55 Group = (45.27/60.66) x 100% = 74.6%

4. Tensile Test Parallel to Grain

For test piece mark CT3 from Table 4.3.

P = 38,000N

$A = 30x30 = 900mm^2$

$\sigma_T = 9.0N/mm^2$

T.S. at M.L., f_t of clear specimens = $43.47N/mm^2$

T.S. at M.L., f_t Group of SSLT = $15.48N/mm^2$

(a) T.S. at M.L = $ft = \frac{38,000N}{900mm^2} = 42.22N/mm^2$

(b) T.S. at L.P. = $ft_{LP} = 9.0N/mm^2$ (from Graph)

(c) $E_T = \frac{\sigma_t}{\epsilon_t} = 18,000N/mm^2$ (slope of the stress-strain curve)

(d) E.R. of SSLT Group = (15.48/43.47) x 100% = 35.6%

APPENDIX 4: PREDICTION OF FAILURE LOADS[15 & 18]

1. Static Bending Test

Data:

Take test piece mark FB3B

Size = 768x132x48mm

W_1 = 4150g

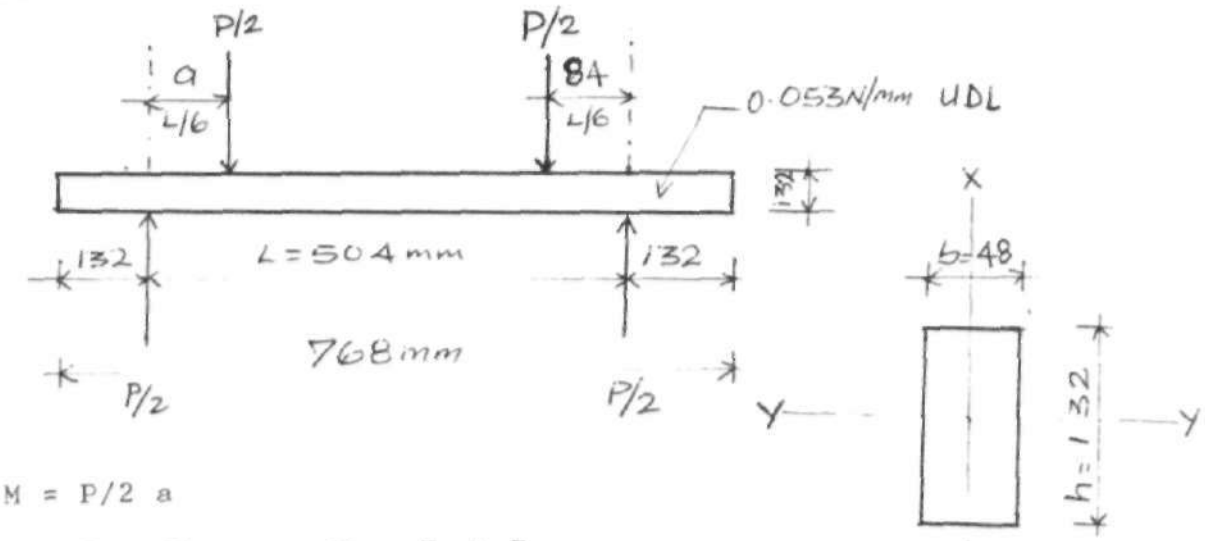
UDL = 0.053 KN/m (0.053N/mm)

Assume that the beam is hinged at support or simply supported and the Timber is N3/50% Khaya-Senegalensis.

M.C. ≤ 18%

E = 10,600N/mm^2

The load be short term. Four point method of loading beam of BS 373: 1957 be adopted. Let L/6mm be distance of load point to support and P, be failure load.



Let M = P/2 a

P/2 a = Z x fbgpar x F_1 x F_4 x F_5

From the above formulae P can be found.

$$M = P/2\ a = \frac{(P - 0.0407)(0.084)}{2} - \frac{0.053\ (0.216)^2}{2}$$

$= (P - 0.0407)(0.042) - 1.2364 \times 10^{-3}$

$= 0.042P - 1.7094 \times 10^{-3} - 1.2364 \times 10^{-3}$

$M = 0.042P - 2.9458 \times 10^{-3}$

$$\frac{M}{Z} \leq fbgpar \times F_1 \times F_4 \times F_5$$

From Table 10 of NCP2: 1973

$fbgpr = 11.20N/mm^2$

$\therefore$ $ftppar = fbtppar = fbgpar \times F_1 \times F_4 \times F_5$

where:-

$F_1 = 1.5$ short term (load duration Table 12 NCP2: 73)

$F_4 = 1.0$ (Rectangular section)

$F_5 = (300/h)^{0.11} = 1.0945$ for $72 < h < 300mm$.

$$\frac{M}{Z} = ftppar = 11.20 \times 1.5 \times 1.0 \times 1.09\,45 = 18.3876$$

$= 18.39N/mm^2$

$M = Z \times fbgpar \times F_1 \times F_4 \times F_5$

$= \frac{48 \times 132^2}{6} \times 18.3876$

$= 2,563,084.3Nmm$

$= 2.5631KNM$

$\therefore Z \times fbgpar \times F_1 \times F_4 \times F_5 = P/2 \times a$

$0.042P - 2.9458 \times 10^{-3} = 2.5631$

$P = \frac{2.5660458}{0.042}$

$P = 61.0963$

$P = 61.10KN$

Thus the safe load, the specimen can carry is 61.0KN. We can

deduce that the failure load is safe load x factor.

Failure load = 61.10 x 3 = 183.30 KN

The Actual upper value of critical load = 180KN.

2. COMPRESSION TEST PARALLEL TO GRAIN

Data:

Take test piece mark C4-55

Size = 475 x 84 x 35

W_1 = 1,150g

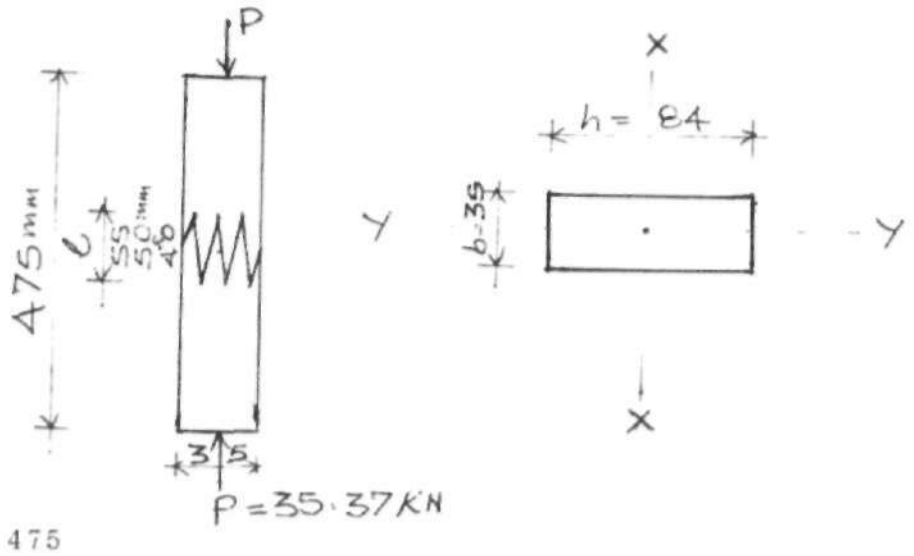
Assume that the strut is hinged at support.

Assume also that Timber is N3/50% Khaya-Senegalensis.

M.C. ≤ 18%

E = 10,600N/mm^2

Let us say that P is axial load and is short term.



Lex = Ley = 475

r_x = 84/√12 = 24.25

r_y = b/√12 = 35/√12 = 10.10

λ_x = lex/r_x = 475/24.25 = 19.59

λ_y = ley/r_y = 475/10.10 = 47.03

From Table 10 of NCP 2: 1973 PP 38 we have:

fcgpar = 9.00N/mm^2

fcgper = 3.15N/mm^2

τpar = 1.40N/mm^2

The permissible compressive stress fcppar = fcgpar x F_c

$$fcapar = \frac{PN/mm^2}{35 \times 84} = \frac{35.37 \times 10^3}{35 \times 84} = 12.03N/mm^2$$

suituation of axial load without lateral loads.

$$\frac{8.62\ E}{cgpar} = \frac{8.62 \times 10{,}600}{9.00} = 100.76$$

100.76 > le/r
100.76 > 47.03

$$\therefore\ F^6 = 1.5 - 0.0870\ Cgpar\ (l)^2 \frac{-----}{E}\ \frac{---}{(r^2)}$$

$$= 1.5 - \frac{0.0870 \times 9 \times (47.03)^2}{10{,}600} = 1.5 - 0.1634$$

= 1.3366

$$\therefore\ fcppar = 9.0 \times 1.3366 = 12.0294N/mm^2$$

Design load = 12.03 x 84 x 35 = 35.37KN

It was observed that during the axial loading of compressive members failure loads ranged between 4 x safe load and 5 x safe (designed) load.

Failure load = 4 x S.L. to 5 x S.L.

Example

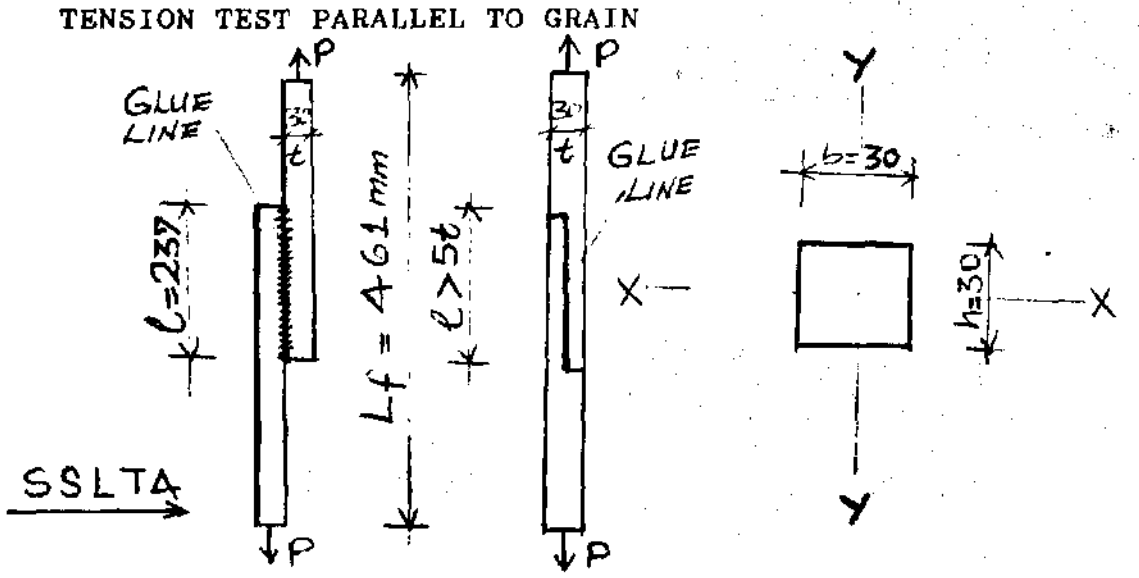
C4 - 55 piece

At 35.37 KN load there was a noise from the internal fibres of

the testing piece and it failed at 140KN.

Failure load = 35.37 x 4 = 141.48KN.

3. TENSION TEST PARALLEL TO GRAIN



Let us choose specimen SSLT4; 461 x 30 x 30

W_1 = 14.50 KN

M.C. ≤ 18%

E = 10,600N/mm^2

Assumptions:-

The ties were axially loaded to failure.

Supports were hinged.

Timber N3/50%

P; axial load with no lateral load and is short term.

Calculations:-

ft∥par = 11.20 N/mm^2 (Table 10 of NCP 2)

F_1 = 1.5 (Table 12 of NCP 2)

F_5 = 1.17 (h < 72mm)

ftppar = ftgpar x F_1 x F_5

= 11.20 x 1.5 x 1.17 = 19.656 N/mm^2

Design load = 19.656 x 30 x 30 = 17.69 KN

The failure load for clear members occurred between 2 x designed safe load and 2.5 x designed safe load.

2 x 17.69 to 2.5 x 17.69 = 35.38 to 44.23 KN

It was observed that the failure loads for the single shear lapped glued joint were between 13KN and 14.50KN less than the safe designed load of the joints.

The testis therefore rejected on this basis, but the values of the clear pieces (unjointed) were adopted for comparison with other works.

APPENDIX 5: GLOSSARY

Assembly joints: Joints for bonding variously shaped parts such as in wood furniture.

Assembly Time: Interval between spreading the adhesive on the surfaces to be joined and the application of pressure to the joint or joints.

Air-Dry Timber: Timber having a moisture content in approximate equilibrium with the atmosphere.

Basic stress: The stress which can safely be permanently sustained by timber containing no strength reducing characteristic.

Boil Proof adhesive: Adhesive that will not fail after many hours of boiling.

Bond failure: Rupture of adhesive bond.

Butt joint: End joint formed by gluing together the square ends of two pieces.

Catalyst: A substance that markedly speeds up a chemical reaction such as the cure of an adhesive when added in minor quantity as compared to the amounts of the primary reactions.

Clamping Pressure: Pressure developed by clamps of various designs to bring joint surfaces into

close contact for glue bond formation.

Curing (Cure): To change the physical properties of an adhesive by chemical reaction, which may be condensation, polymerization, or vulcanization; usually accomplished by the action of heat and catalyst, alone or in a combination, with or without pressure.

Defect: Any feature that lowers the technical quality or commercial values of timber or other material that may therefore lead to its rejection or to its relegation to a lower grade.

Density: Weight per unit volume, generally expressed in kilogrammes per cubic metre. It is necessary to specify the moisture condition of wood at the time weight and volume are determined.

Elasticity: The capacity of bodies to return to their original shape, dimensions, or positions on the removal of a deformation force.

Elastic Limit: Limit beyond which it is impossible to continue applying a load without establishing a permanent change in shape.

End joint: A joint made by gluing two pieces of wood end to end, commonly by a scarf or finger

joint.

End joint Efficiency: Percentage ratio of the strength of end joint to the strength of unjointed timber of the same cross-section and specie containing no strength reducing characteristics.

Fibre stress at Limit of Proportionality: Maximum stress to which the material can be subjected to, under an applied load without being deformed permanently.

Fibre stress at Ultimate load: Maximum stress to which the material can be subjected to, under an applied load so as to cause failure.

Finger joint: An end joint made up of several meshing fingers of wood bonded together with an adhesive.

Flexibility: The ability to bend, freely and regain normal shape.

Gluability: Term indicating ease or difficulty in bonding a material with adhesive.

Glue: Any natural or synthetic adhesive; any sticky substance.

Glue line: The layer of adhesive affecting union (bond) between any two adjoining wood pieces or layers in an assembly.

Gluing Pressure: Pressure to bring the surfaces spread

with glue into close contact for bonding.

Grade Stress: The stress which can safely be permanently sustained by timber of a particular grade.

Hardwood: A conventional term for the timber of broad-leaved tree, and the stress themselves, belonging to the botanical group Angiospermae.

High-frequency curing: Setting or curing adhesive with high-frequency electric currents.

Internal Stress: Stresses set up from internal conditions, such as differential shrinkage, aside from external loads applied to a member.

Limit of Proportionality: Limit to which the deformation or strain of a material is proportional to the applied load.

Melamine: A white crystalline compound made from calcium cyanamide.

Melamine resin: A synthetic resin made by combining melamine and formaldehyde.

Member: Structural Component which may be either a piece or solid timber or built up from pieces of timber, plywood, et al (e.g., floor joist, box beam, member in a truss et al).

Modulus of Elasticity: A measure of the relation between stress

and strain within the limit of proportionality, providing a convenient figure for expressing the stiffness or flexibility of a timber.

Modulus of Rupture: A measure of the ultimate bending strength of timber for that size of sample and that rate of loading. This is actually the equivalent stress in the extreme fibres of the specimen at the point of failure.

Natural adhesive: Adhesive produced from naturally occurring products (organic) such as blood and casein (milk).

Nominal Lumber: The rough-sawned commercial size by which lumber is known and sold in the market, for example, a 50mm x 100mm (a 3 by 4).

Pitch: In finger joints, the distance between midpoint of one fingertip and midpoint of the adjacent finger tip.

Potlife: Usable life of adhesive after mixing.

Preservative: Any substance that, for a reasonable length of time, is effective in preventing the development and action of wood-destroying fungi, borers of various kinds, and harmful insects that deteriorate wood when the wood has been

properly coated or impregnated with it.

Resin: A solid, semisolid, or pseudosolid organic material that has an indefinite and often high molecular weight, exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally.

Room-Temperature-Setting adhesive: An adhesive that sets at temperatures between 20° and 30°C (68° to 86°F).

Scarf joints: Sloping joint between ends of two wood members.

Shear: The relative displacement of woody tissues following fracture as a result of shearing stress.

Shear parallel to grain: Stresses applied in a manner to cause shear failure along the grain.

Shear strength: The capacity of a body to resist shearing stress.

Soft wood: A conventional term for both timber and coniferous trees belonging to the botanical group Gymnospermae.

Starved joint: A joint that is poorly bonded because insufficient adhesive has remained in it as a result of excessive pressure on the joint or too low viscosity, or both; the

adhesive is forced out from between the surface to be joined.

Stiffness: Property of a material by means of which it tends to resist deformation when acted upon by external forces.

Strain: The distortion or deformation of a material caused by an applied load. It is expressed as the ratio of change in dimension of the material to the original dimension.

Strength: In relation to a material such as wood refers to the ability of the material to resist external forces or loads tending to change its size and alter its shape.

Stress: The internal force within a material that tends to resist changes in size or alteration in shape caused by an applied external load. It is expressed as a ratio of the applied load to the area over which the load is applied.

Synthetic Adhesive: Adhesives produced by chemical synthesis.

Tensile Strength: The capacity of a body to sustain tensile loading (resistance to length wise stress). In wood, tensile strength is high along the grain and low across the grain.

Tension Parallel to grain: Stress on a material (wood) in the long direction of its fibres.

Timber: Wood in a form suitable for construction or carpentry, joinerly or for reconversion for manufacturing purposes.

Truss: A frame or jointed structure designed to act as beam of long span, while each member is usually subjected to longitudinal stress only, either tension or compression.

Urea: A soluble crystalline compound made from carbon dioxide and ammonia and condensed with formaldehyde to produce formaldehyde resin.

Wood failure: The rupturing of wood fibres in strength tests on bonded specimens, usually expressed as the percentage of the total area involved which shows such failure.