University of Southern Queensland
Faculty of Engineering and Surveying

TESTING OF CURRENT FLOORING SYSTEMS AND MATERIALS

A dissertation submitted by

Aaron John Neubauer

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ABSTRACT

This dissertation researches the types and uses of manufactured wood products and aims to test the effect of real world environment that the various products may experience during the early stages of construction. The residential construction industry, within the local area, is fastly growing, and with tighter deadlines more construction efficient products are being created so that profits can be maximised.

New products must meet a criteria outlined in the Australian standards before they can be used in construction. The most common principle used in the design of manufactured wood products is use a common light wood, remove faults and imperfections and bond it together to make a strong lightweight product. This results in the reduction of material costs and labour costs, as the products weight far less and is easier to work with.

The two most common categories of manufactured wood products are, Laminated Veneer Lumber (LVL) and Glued Lamination (GluLam). Other products that use design principles based on other material designs have emerge recently and are developed enough to become viable replacements for traditional solid woods.

The inherent problem faced by all manufactured wood products that are bonded, is that the bonds between the wood are susceptible to moisture, UV rays and cyclic temperature change. These elements are mostly experienced during the construction stage before suitable coverings are constructed ei. roof.

To combat these elements, manufacturers specify protective methods to reduce, or even halt, the effects. The most common method is the use of paint layers. A particular product literature document shows that an oil based primer followed by two coats of external acrylic finish should provide adequate protection. This method of protection, along with some variations will be tested on manufactured wood products to find its effectiveness.

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Aaron John Neubauer
Student Number: 0050009508

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Date

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E_m	=	Modulus of elasticity
MPG	=	Machine Proof Graded
AS	=	Australian Standards
l_1	=	Distance between the centres of the supports in millimetres
b	=	width of the test piece in millimetres
d	=	depth of the test piece in millimetres
$F_2 - F_1$	=	Increment of load on the straight section of the load-deflection curve in newtons, F_1 shall be taken as 10±5% and F_2 shall be taken as 45±10% of the maximum load
$a_2 - a_1$	=	Increments of deflection taken at the middle of the test piece corresponding with $F_2 - F_1$

CHAPTER 1

INTRODUCTION

1.1 Outline of the study

The main aim of this project is to gain a greater understanding of the mechanics of wood and manufactured wood products. This will include researching the construction of manufactured wood products and how they are used in industry.

Most engineered wood products have technical data sheets and material properties publish with them. Some of the technical data from these sheets will be used to compare with test results obtained from testing relevant samples. Due to the nature of the materials used in manufactured wood products, different levels of humidity, UV light and temperature can affect the performance of the products. The samples will also be tested against the environment to determine the effectiveness of different wood protection agents.

1.2 Introduction to Structural Wood

The idea behind MWP (manufactured wood products) was to take a mass produced, efficiently grown source and create products that could replace timbers of larger size and strength. These solid timber members of large cross section were used to support large loads and used in places of visual focus. The larger, solid timbers commonly came from trees that were more than one hundred years old in precious natural habitats. Due to the environmental damage caused to various habitats by the processing of these timbers, it was concluded that the habitats, and everything within them, be protected by legislation and law. This limited the source of high load bearing timber and forced the use of smaller members of smaller span and steer construction to other materials such as steel for the residential housing industry.

To combat this, engineers needed to create products to replace these timbers that are now protected from use. The product had to be cost effective and viable. Research found that some of the not so desirable properties of large solid timbers, such as weight, warping, cupping, twisting and crack, diminished with the laminating processes. Common, fast growing soft woods are used for the basis of these products as they are easy to obtain and prepare and readily grown in most soils.

The first use of manufactured wood products in Australia occurred in 1907. It took the form of veneer and plywood production for use in pianos. Veneers were sliced and sawn and later rotary peeled from logs. During the 50's and the 60's synthetic glues and adhesives became increasingly popular for use in modern plywoods. This concept was later used to make thicker members up to 75mm for structural use (although custom sizes could be manufactured).

The veneers are glued so that the fibres are parallel to tension and compression forces when the member is in its final resting position. This concept was developed and is now known as Laminated Veneer Lumber (LVL) and is one of the oldest structural manufactured wood product designs used.

Another method that was developed was the use of short timber sections laminated together stacked horizontally along the length of the beam. The use of dressed members Veneer Lumber's construction does not produce a visually pleasing product

1.3 Research Objectives

The primary objectives are to compare strength related properties of different types of timber to the relevant Australian Standard. The five main classifications of wood types that will be tested are:

- Softwoods
- Hardwoods
- GluLam (Glued Lamination)
- LVL (Laminated Veneer Lumber)
- Composite cross-section (I-beam, box section)

Softwoods and hardwoods, being made from a section of a felled tree and have a set of standards. Any solid timber section that is intended for use in structurally purposes is given a ‘grading’. Most of the grading tests involve machine bending. For this project, different samples of graded hardwood and softwood will be tested in a similar fashion to investigate if they graded correctly and conform to the standards.

Manufactured wood products, such as GluLam, have a grading system in which products will fall into a category. The manufacturer is to release a product worksheet that outlines strength properties so that the product meets a minimum standard referenced by classification. The product sheet includes strengths and engineering properties for use in calculations and some provide reference sheets to make selection of the correct appropriate member for a particular job.

It has been found that eh resins, glues and adhesives used, are susceptible to the natural elements. Manufacturer’s often specific methods to protect products from the natural elements and to ensure design properties. The method in which the protection is provided varies from manufacturer to manufacturer and some manufacturers provide several options depending on the finish that is needed.

Various products, subjected to availability, will be tested for strength against a selected method of protection chosen from the technical data. Also, several different methods of moisture protection will be tested on the same produce to give a comparison. These results will then be used to draw conclusions on the products tested and the effectiveness of the recommended service practices outlined in the product worksheet or Australian standard.

1.4 Dissertation Overview

This dissertation describes the work, research and testing undertaken in order to meet the aims. Research into uses of manufactured wood products and the manufacture of various products was conducted to find suitable samples to test. Many samples in various different conditions were tested. These results were compared and recommendations made. Conclusions were made on various findings and any areas of further research discussed.

CHAPTER 2

AN OVERVIEW OF STRUCTURAL TIMBER

2.1 Introduction

For residential dwellings, structural timber is the most efficient material to use. The positives out weight the negatives for this application. Timber is easily harvested and refined. It is easy to work with and is a renewable resource. Timber gives a warm natural feeling and various species yield different shades and colours, which when prepared, can be used in areas of visual appeal.

The loads and forces encountered in residential construction are relatively small. If one were to design a member out of concrete or steel,

Timber products can be divided into two categories. The traditional solid sawn timber that is made from a single piece of wood that had been shaped appropriately, and manufactured wood products (MWP) which is a composite member constructed from small sections bonded together.

2.2 Uses

The properties of timber allow it to be used in a variety of applications. The most common use is of structural nature but various properties make timber suitable for other uses such as sound deadening, acoustical instruments, insulation and even flavouring of beverages and food.

Timber members can be used as compression members, tension members, torsion members, loaded members or unloaded members. Timber can be used in many applications, loaded in various ways. Timber is most effective in compression if the forces are parallel to the fibre orientation and most shear resistant when the force is applied perpendicular to the fibre orientation.

Figure 2.1 The use of LVL in a roof truss

2.3 Advantages

Timber use has several advantages over other materials such as steel and concrete. Concrete is only used as foundations and is impractical to use in walls and trusses. Timber is renewable resource, meaning that it is a natural resource that consumed at a slower rate than the rate at which is regenerates. It requires less energy to process the raw materials into usable timber making it far cheaper to refine. Commonly used structural softwoods, such as various species of pine, can be grown in plantations that mature for harvesting in a matter of years.

The use of plantation timber can also be seen as a benefit to the environment. As a tree grows, it absorbs carbon (from carbon dioxide gas) as part of its natural growing process. Normally, a tree will grow absorbing carbon until it ages and will eventually die. Once a tree dies, it begins to breakdown releasing nutrients like all organic matter. The carbon that was absorbed during the growing cycle of the tree is released back into the atmosphere when a dead tree decays or is forced to decay by means such as burning. Plantation trees are harvested at the peak of a trees carbon absorption cycle. From here, the trees are refined and prevented from natural decay. This locks the stored carbon within the timber hence reducing the amount of emissions within the atmosphere.

Timber is also one of the most fire resistant structural materials. Timber does readily burn, but it leaves behind by-products of its combustion. These deposits of residue help impede the flow of oxygen, the primary component in combustion, and stifle the access of new fuel. The residue acts as a protective layer or casing to the timber increasing its fire resistance and increasing the member’s effective fire life. This phenomenon allows a timber member to withstand heats that would easily cause a steel member of similar loading to fail.

Timber is most effective if the compressive or tensile forces are parallel to the fibre orientation and most shear resistant when the force is applied perpendicular to the fibre orientation. These properties are often utilised in manufactured wood products by orientating the fibres of sections in areas of stress so that the loading conditions are in favour of the sections properties.

2.4 Solid Woods

Solid woods are timbers that have been sized out of one piece of wood. These timbers may have undesirable elements in them taken from the log in which they were sawn down from. Some of these imperfections include knots, splits, shakes and the heartwood of the original tree. In long lengths with smaller cross sections, warping can be a big problem. There has been examples of 75mm × 50mm radiata pine that has twisted more than 360° along a 6 metre length.

There are two types of wood available, hardwoods and softwoods. The use of the names hard and soft is not related to resistance to impact, colour or density, but with the microscopic cell structure within the timber.

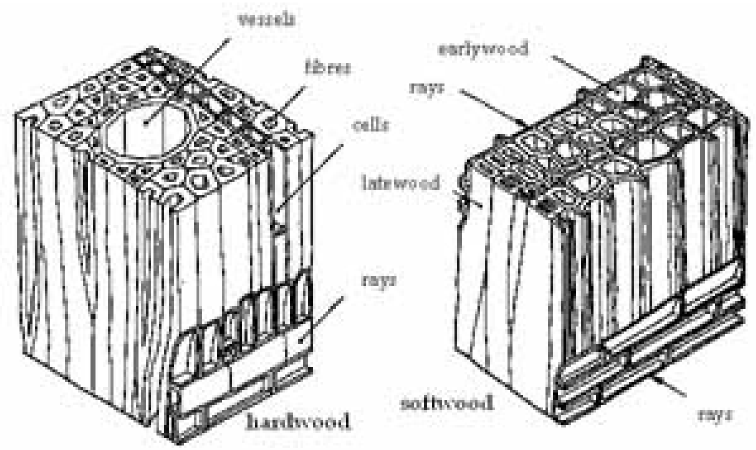

Figure 2.2 The different sell structure of hardwoods and softwoods

Solid wood has its own unique grading system. There are two types of grading and they are the F series and the MPG series. The F series grades whole harvests of plantations at a time. Samples representative of the plantation population is tested and the results determine what grading that particular harvest will yield. Some examples of naming are F4, F7 and F14. Each F series grade has a specific set of design properties that define it.

The MPG series is a grading system that requires each piece to be tested to a proof load. MPG stands for Machine Proof Graded. Each piece is feed into a machine and a proof load is applied at a certain rate. The deflection from this loading is then used to grade the wood. Once a member exceeds a given size, this test cannot be used. The necessary factors and limits for this method of grading are documented by the Australian Standards. It is important to note that grading by this method means that every piece of timber has been rapidly loaded and may have weakened the overall product.

Figure 2.3 Hardwood used as bearers and joists to support a deck

2.4.1 Hardwood

The hardwood cell structure consists of non porous fibres that are densely packed together which are feed nutrients by larger vessels. These vessels are also responsible for transporting nutrients from the root system to the foliage and throughout the tree itself. The ratio of the vessels to the fibres varies from specie to specie. The density of the non porous fibres gives hardwood strong structural properties and a strong resistance to chemical attack and moisture penetration as well as high impact resistance. These properties made hardwoods ideal for applications such as wine barrels and for use in coastal areas such as docks and wharfs. The ability to repel moisture saw the use of hardwoods in early boat construction and is still used today.

The increased fibre concentration increases the density and some species of hardwoods are very heavy per unit volume making larger pieces cumbersome to move, cut and join. An upside is this high density increase the jointing capabilities meaning that it can retain nails and glues better.

Unlike the manufactured wood products, hardwood's strength properties are generally unaffected by weather instead the shape of the timber may warp. Some material properties may change during seasoning such as it may become more brittle. Any changes in shape, such as bowing or twisting, are attributed to the seasoning process. Seasoning is the process in which the cell bound moisture is removed over a period of time. The time taken to season a piece of timber is dependant on many variables and is impossible to predict. The amount of moisture that is removed for a piece of timber depends on local humidity and temperature.

The cells contain a high percentage of water in their body mass. When this water is removed, the cells may change volume which can affect the overall shape of the timber. Very few defects appear in pieces of hardwood during seasoning. This is due to the density of the fibres and that they are non porous meaning there is little moisture present in the fibres resulting in a smaller change of volume.

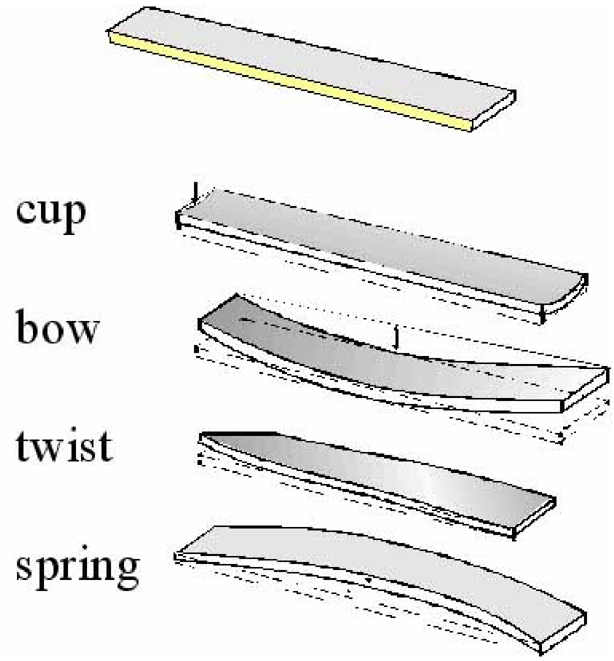

Figure 2.4 Warping in solid timber

Warping resulting from seasoning can be a problem as it may cause loads to become eccentric creating forces that the member was not designed for and may result in a failure. Seasoning may also result in how well the timber can be bolted or nailed and may change the mode of failure. The Australian standards recognise these factors and present a worse case scenario for design purposes using timber.

A solid hardwood timber member is the strongest structural timber per unit weight. With a dense cell structure, hardwood can resist impact and chemical attack, but also is usually heavy per unit volume. These factors make it costly to process large members. The variety of grain colours between species has lead to hardwoods being used in areas of visual attraction. It if for these reasons, hardwoods are generally used in areas where a structural purpose must be meet and an accent on visual aspects is needed, such as posts in an outdoor area or as decking near a pool.

2.4.2 Softwoods

All the cells within softwoods are porous and act as conduits transporting vital nutrients from the root system to the foliage. The structure is similar to a bunch of straws, each one can flow nutrients. This ‘open’ cell structure results in less dense timber. This open cell structure is very permeable allowing treatments and moisture to penetrate deep within the member. This property allows glues and adhesives to be readily absorbed and to form good bonds between sections of softwoods used in manufactured wood products.

The low density of softwoods gives them a lighter colour than that of hardwoods. Structural strength properties are generally less than that of hardwood. The most common locally used species in residential house construction are cypress pine and radiata pine. Both these species can be grown to harvesting size in 5 to 8 years. This is common with most softwood species as little nutrients are required per unit volume to grow allowing the trees to grow quickly.

This makes softwood pine the one of the most profitable high yield plantation timbers. It can be mass produced in a few years and requires less fertilisers and nutrients to grow. It can be seasoned, ready for structural use, relatively quickly with less energy required to do so.

Softwoods porous cell structure means that there is generally more moisture per unit weight than hardwoods when the timber is felled. To aid in the quick removal of moisture most softwood timber is kiln dried before use. Kiln dried timber is timber that has been essentially baked in an oven like setup in an attempt to remove as much moisture as possible. This process can only be guaranteed to partially season timber as kiln drying is a quick and dirty method of removing moisture and cannot remove all the moisture from the all the cells over such a short period of time. Full seasoning can take up to a year depending on some species.

Since the cells are predominately water, when removing this water, the cells may change volume and some properties. The raw timber is sawn from the log while still 'wet' and will reduce and change dimensions until an equilibrium is found with the internal moisture content and surrounding environment. This can also lead to warping as the cells in softwood loose more water than hardwoods and as a consequence will change more. See figure 2.3.

Softwoods material properties are affected by seasoning more than hardwoods. Some softwood species, when seasoned, can become very brittle and does not take much impact to cause shakes, splits and crack to form. This can affect the mode of failure and how workable the timber is.

For structural use where the objectives are to meet the demand and the final product is purely structural, softwood is the most efficient product. It can be grown, harvested and process for use relatively quickly and it's a lightweight, workable material. Less costs needed to grow softwood mean less costs to purchase processes softwood. It is for those reasons softwood is the most used timber in residential construction.

2.5 LVL (Laminated Veneer Lumber)

LVL is the abbreviated form of Laminated Veneer Lumber. LVL is the oldest manufactured wood product design. The design originated from the use of veneers bonded together. Veneers are thin sheets of wood, up to 3mm thick, either sliced from a larger section or peeled by a rotary peeler <reference figure>. The most common application of veneers is for furniture and kitchen finishes were the frame or carcass is made from a cheap material and is clad in high quality wood veneers to give the impression of a solid wood article.

The first use of veneers for a structural use was in plywood, which is a manufactured wood product in which several veneer sheets are bonded together with the fibres running at various angles to each other so that board is strong in many directions. Plywood is still used today and some common sheet thicknesses vary from 3mm to 21mm in increments of 3mm. Plywood is commonly used as a bracing sheet to transfer horizontal loads from the top of a wall to the base of the wall, which is fixed to the foundations. The method of manufacture allowed sheets to be made in dimensions that would be impossible to process out of solid wood.

When the need to for cost effective wood structural members arose, LVL was one of the first methods to be adapted. The same principles are use as in plywood construction except that there are many more veneers layered together and the fibres are orientated such that they imitate a solid wood beam. The fibres are orientated to be parallel with the tension and compression forces, simulating a solid wood beam, to provide maximum strength and shear resistance. LVL sheets are produced roughly 1200mm wide and the length is determined by the machinery used. Standard thicknesses of 65mm and 75mm are common but custom thicknesses can also be made to order. From the large sheets, standard depths and lengths are cut. As the working base is produced in a large sheet, custom shaped billets can be cut. This allows for any shaped structural member to be cut as long as it fits on the production sheet allowing for flexibility within structural timber design.

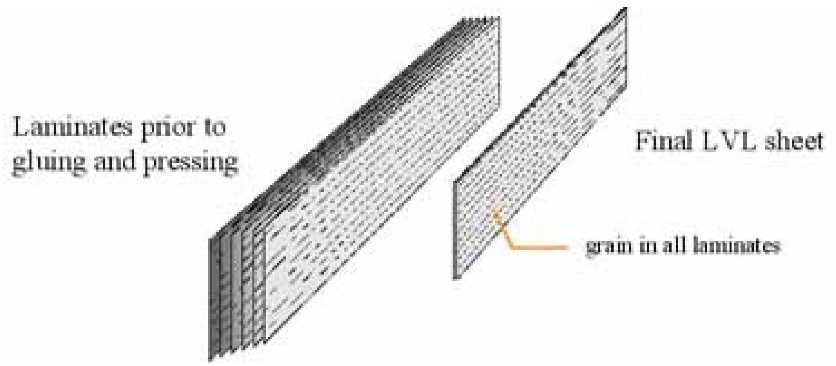

Figure 2.5 Exploded diagram of LVL

LVL is manufactured in soft wood only as hardwoods are too difficult to produce into veneers and general become very brittle when reduced to small thicknesses. Due to the roughness of the manufacturing process, LVL are not considered a visually pleasing product. The veneer creation process prevents any visual imperfections from being avoided and removed and consequently is included in the final product.

The finishes that can be applied to LVL are limited. Due to the sensitive nature of the adhesives to moisture and UV light used in LVL, if any part of the LVL beam is to be exposed to the outdoor environment, it must be properly protected to prevent degradation of the bonds, as the glues and adhesives are water soluble. Protection must adequately prevent the entering of moisture into the LVL as any moisture would be quickly absorbed by the softwood and spread throughout the LVL member and could cause mass failure of the bonds.

It is important to note the effect of humidity on the adhesives and that the Tropic of Capricorn circle of latitude is the upmost geographical limit in which manufactured wood products can be used and effectively retain strength. Above this geographical line and the natural environment is considered so harsh and changing, that the members cannot be sufficiently protected against humidity entering the member.

Overall LVL makes good use of timber, ei. little waste left over, to make a more uniform structural member in lengths and sizes that exceed that of solid wood. Also manufacturing process allows for exotic designs which can include curves, tapers, cogs and other shapes. For this reason, LVL becomes a flexible product for structural use when solid timber becomes costly.

2.6 GluLam (Glued Lamination)

GluLam is the abbreviation of GLUed LAMination. Almost any other beam style that does not fit into LVL criteria will be considered to be of GluLam design. GluLam consists of short timber sections laminated together with adhesive. The members are orientated horizontally along the length of the member. Construction of GluLam beams is similar to that of fibre composite member construction. Sections are progressively added to the beam from the bottom up. The sections are then pressed and adhesives left to cure.

The use of short members in the construction allows cambers and curves to be moulded into the member. This is useful as cambers can be used to reduce the effect of service load and eliminate deflection. A downside is that the cross section of the member must remain uniform, ei. no tapering. Soft wood is commonly used for the short members as softwoods absorb the glues better providing for a stronger bond.

GluLam are mainly used in areas of visual appreciation since the members used to construction them are imperfection free and are dressed to a smooth surface. This creates an ideal surface that can be stained or varnished to enhance the various shades of timbers present within the GluLam member.

Figure 2.6 Samples of GluLam beams

GluLam beams, like many manufactured wood products, need to be protected from the natural elements to prevent degradation of the bonds. Again, protection is only needed where direct exposure to the natural elements occurs. Some hardwood variants of GluLam beams are more resistant to weather but still require some protection. Unlike LVL, GluLam beams have less adhesive per unit weight as the majority of a GluLam member is made up of wood sections. This makes GluLam more suitable for exposed use than LVL as the bonds are more protected by the timber sections. Protection is still required if a GluLam beam is exposed, it is just the preferred choice for external use of manufactured wood products.

It can be seen that GluLam products are most suitable for areas of visual appreciation while still remaining a structural member. GluLam allow for custom members to made buy placing hardwood sections in areas of high stress and even using metal reinforcing.

2.7 Other Designs – The I Beam

Many design ideas have crossed over from other conventional construction methods into manufactured wood design, such as using stronger wood in areas of high stress and pre making beams with camber in them. By far the most intuitive design is the use of an I-shaped cross section similar to that of a steel universal beam. The design use of this I beam is primarily for the support of trafficable floors for living under bending about the x axis of the design.

Figure 2.7 Samples of the I-Beam design

The main issue with trafficable floors is impact deflection. Impact deflection has to be keep to a minimum as even the smallest deflection when walking is exaggerated by human senses. If a floor deflection is too much upon impact (walking) then people will feel unsafe and will avoid using that floor. From design calculations, the only way to prevent impact deflection is to increase the depth of a member. This made traditional rectangular cross sectioned beams, bearers and joists large in dimensions just to meet deflection limits. Much of the cross section is not under stress in holding loads and makes members large and cumbersome when the spans increase.

The I beam design allows much of this wasted cross section to be removed and still meet the deflection and loading limits. This removal of unnecessary material reduced the weight per unit length and the amount of material required to much such a beam making it more cost effective and efficient to work with. Softwood is commonly used in this product to further reduce weight and manufacturing costs. This design works that well, larger spans can now be used, eliminating support beams and posts and reducing costs.

The flanges are made separate to the web and are usually solid as using other manufactured wood products as flanges has been know to cause serviceability issues. The web is commonly made of structural plywood or chipboard (chips of wood pressed and glued into sheets). The web is then glued into a groove in the flanges to increase the bond surface area.

The strength of this product is derived from the bonds. Analysing the design under bending load, the critical point is the shear stress where the flange joins the web. This is why the web is recessed into the flange to improve shear resistance by increasing the bond surface area. It is for this reason that this product is to be protected from the effects of weather and meet strict criteria in order to guarantee design strength. One such criterion is the minimum distance from natural ground to the bottom of the member. Also the I-beam is not to be used for any other purpose other than trafficable floor support members. Consequently, this product is prohibited from external use and usage north of the tropic of Capricorn due to humidity issues.

The I-beam design has revolutionised the construction of residential suspended flooring systems. Its design allows for larger spans of floors to be achieved with one member compared to that of conventional solid wood systems. It is also a very lightweight design and beams of substantial length can be handed and fitted by a single worker reducing labour costs and time consumption. Costs for the beam itself are minimised by using cheap, readily available softwood as the base material. The only disadvantage to this product is that it has been specifically design for flooring and has very few other applications.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter provides an overview or the steps taken to obtain the results for comparison. It will describe sample selection and preparation, sample exposure and test conditions.

Several products of various designs were chosen for testing covering solid wood and manufactured wood products ranges. From these samples, a suitable length was cut. In order to achieve suitable results and to reduce the likelihood of rolling during testing the dimensions were keep conservative at an approximant height of 165mm and width of 65mm. The testing machine used has a capacity of large lengths but for this testing, lengths were kept to a minimum of 2400mm.

Each product has been graded or has design data stating material properties. The most common design parameter used in timber design is modulus of elasticity.

3.2 Sample selection

Before any sample types were decided upon, the specifications of the bending test machine we're researched. Aspects limiting the size of the samples such as ram travel, physical room to manoeuvre samples, the risk of the sample rolling during testing and suitable spacings of the supports were taken into account. After these factors were analysed, the ideal dimensions were keep conservative at 165mm in height, 65mm wide and a minimum length of 2400mm to facilitate for at least 2300mm support spacings. Samples were selected based on these dimensions.

From researching type of wood products it was found that there are five main categories. These are softwood, hardwood, GluLam, LVL and other composite shapes. As this project was being undertaken in local conditions, it seemed suitable that only locally supplied products be tested. The main local brand of manufactured wood products is Hyne Timber. There are many local solid wood merchants in the district and it was decided upon to use the largest timber merchant, Simon Pty Ltd for the softwood and hardwood samples. Simon Pty Ltd also supplied the manufactured wood products.

3.2 Sample Preparation

Consulting the technical data sheets provided by the manufacturer, Hyne Timber, for the Hyne 18c GluLam products, a minimum external use coating method, including some variations were chosen, to be tested and compared for effectiveness. There was no need to provide protection to the solid timber sections as there is no specific data concluding that it is required to aid in retaining strength. This would help amplify warping that may occur due to the seasoning process. The I-beam members were not designed for any external application, hence no coatings were applied to any members. One sample was exposed to see any effects. In summary, there were samples from each type un-protected and exposed to the weather, as well is three coating variants applied to the three different GluLam and LVL beams. Control beams of each type were stored out of the weather and in a controlled environment for comparative testing.

For this experiment, paint based protection was used as it is the most common and easy method of providing protection. The Technical data sheet provided stats that one coat of oil-based primer followed by two coats of high grade acrylic finish is required to ensure full design strength. This was applied to one of the LVL and GluLam samples. The two other coating variations are one coat of oil-based primer and samples with one coat of acrylic primer. Primers were selected over finish grade paint as finish grade paint is not formulated to penetrate and seal timber but instead to provide a film. A list of the samples and their coatings can be found below.

	CONTROL	EXPOSED			
	No coating	No Coating	Oil based primer, Acrylic finish (OAA)	Oil based primer (O)	Acrylic primer (A)
Softwood	x	x			
Hardwood	x	x			
GluLam	x	x	x	x	x
LVL	x	x	x	x	x
I-Beam	x	x			

Table 3.1 List of samples and coatings

3.3 Sample Exposure

Once the samples were prepared, the exposed samples were spaced so that the maximum amount surface area was exposed to the effects of the climate. The samples were left exposed for a period of four weeks to simulate the conditions in which such members may be subjected to during the construction phase of a residential building. This phase would usually be from when the member is erected to when it is covered by a suitable roof and consequently full loaded.

During this exposure period several storm events occurred as well as temperature variations of up to 25°C over 4 hour periods. This provided a good range of relatively extreme weather events in the local area and season. Basically, all the worst elements that the samples could be exposed to occurred within the exposure timeframe.

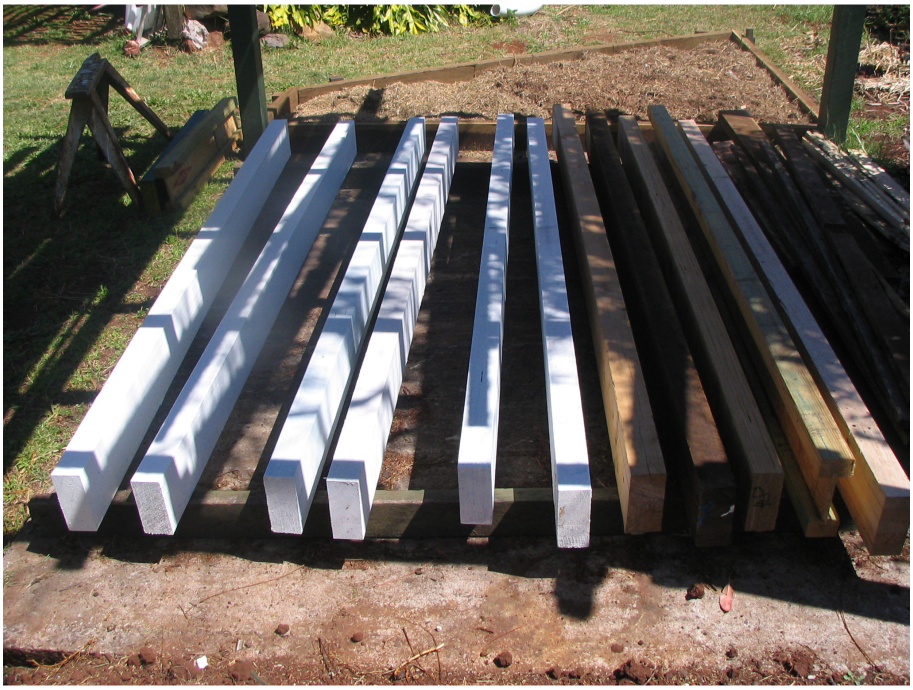

Figure 3.1 Prepared samples being exposed to the elements

3.4 Sample Testing

The samples were tested for bending strength by means of a three point bending test. This test would allow the modulus of elasticity to be calculated and compared. The two supporting rollers were spaced 2230mm apart. This allowed a minimum of 85mm overhang to allow for change in length during load deflection. The Instron Testing machine could apply up to 250kN to a test piece which was more than adequate to test the samples to destruction.

To prevent any sudden collapse, tipping or failure, the sample was loaded at a set deflection per unit time, all samples were tested at 10mm/minute stroke. To ensure no rolling occurred, safety rollover bars were used to stabilise the sample. Samples were then individually tested and load-deflection charts recorded. Results were recorded by the DATA Logger 5000.

CHAPTER 4

DATA ANALYSIS AND RESEARCH RESULTS

4.1 Introduction

This chapter will present the results of testing, calculations and a comparison of the results. A discussion will also be presented discussing constructive criticism on testing. As the different types of samples are constructed using different techniques, the different modes of failure and loading patterns will be discussed comparatively within each sample type. Before testing, each sample's height and width was accurately measured to 0.1mm accuracy.

For the rectangular cross section sample, an adapted formula from AS/NZS 4266.5:2004 was used to calculate the modulus of elasticity from the three point bend test.

$$E_m = \frac{l_1^3 (F_2 - F_1)}{4bd^3 (a_2 - a_1)}$$

Where

l_1	=	Distance between the centres of the supports in millimetres
b	=	width of the test piece in millimetres
d	=	depth of the test piece in millimetres
$F_2 - F_1$	=	Increment of load on the straight section of the load-deflection curve in newtons, F_1 shall be taken as 10±5% and F_2 shall be taken as 45±10% of the maximum load
$a_2 - a_1$	=	Increments of deflection taken at the middle of the test piece corresponding with $F_2 - F_1$

The modulus of elasticity was calculated for several different points within the tolerance stated above. An average was calculated. This was done to eliminate small differences present in the load-deflection curve. All calculations and plots were completed in Microsoft Excel.

4.2 Softwoods

Only two samples of softwood were tested being the control beam and the exposed beam. The samples that were tested are visual grade F7 cypress beams. This means that these beams came from a plantation that was deemed to be of F7 grade by means of selective testing of some samples from within the plantation. F7 also indicates that the timber is required to have a relative modulus of elasticity of E = 7900MPa.

4.2.1 Control Sample

Upon testing the beam, loading and deflection where constant until the timber's maximum strength was reached. No tapering of the plot is present, just sudden failure once the peak had been reached. After the peak was reached and failure had occurred, the member regained some strength on continued to deflect holding a constant load. It is important to note that the peak load is not as high as the exposed sample. This is due to a know imperfection within the tension area under the loading point. This is an example of what manufactured wood products can remove.

The controlled environment in which the beam had been kept prevents the beam from becoming fully seasoned. This resulted in a semi brittle failure which saw the fibres tear and splinter slightly but was contained relatively close to the loading point. This semi seasoning can be seen in the retained strength after the initial failure. In the graph the retained strength is higher than that of the exposed beam.

Figure 4.1 Failure of the control softwood sample

4.2.2 Exposed Sample

The loading and deflection were similar to that of the control beam. To tapering occurred or was small enough to be negligible. The peak strength however was much higher than that of the control sample. This is a result of few imperfections near areas of high stress.

The effect of seasoning can be seen when comparing the retain strength after the initial failure and the mode of failure. The images taken were after the load was removed so the splits and shakes are not as defined. At the point of the initial failure, sudden splits occur and developed along more than half the sample propagating from the center out. This is a result of the brittle failure induced by seasoning. Once this initial failure occurred, due to brittle wood fibres, the retained strength was less than that of the control sample. This is because seasoning reduces the ductility within the fibres and increasing inter-fibre friction resulting in a less ductile member.

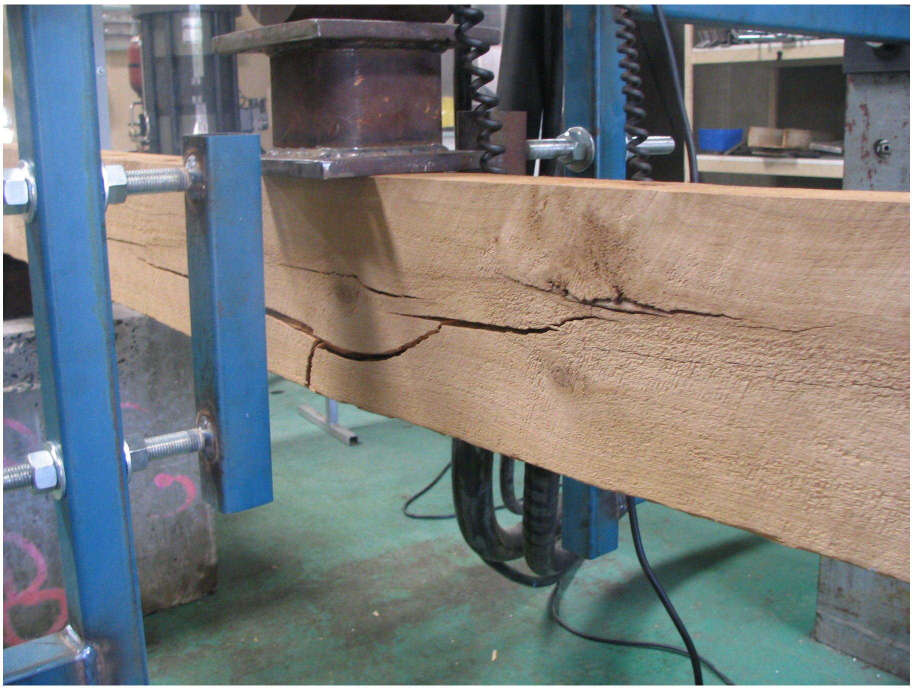

Figure 4.2 Failure of the exposed softwood sample

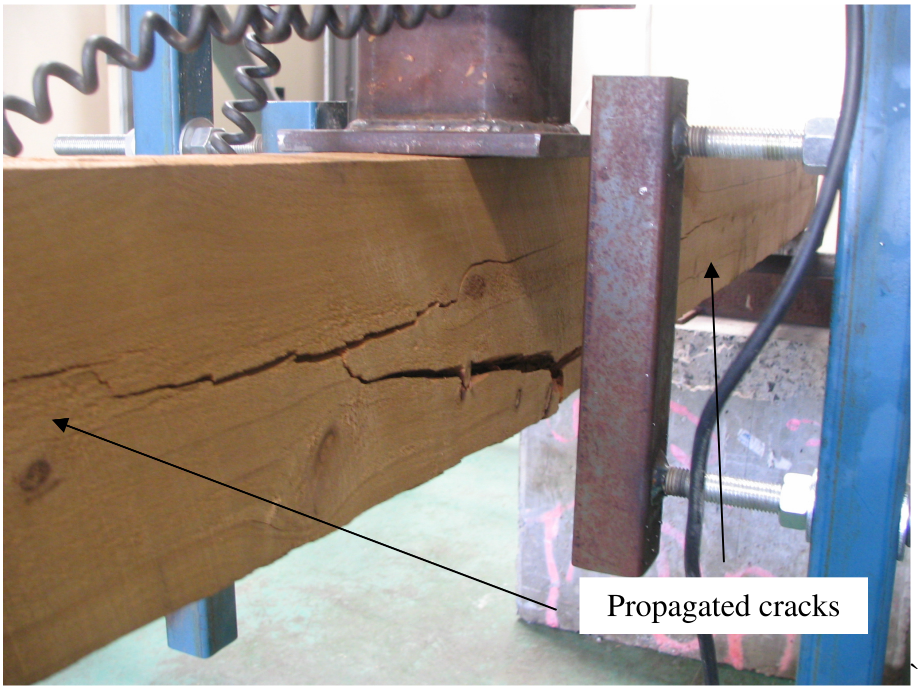

Figure 4.3 Failure of the exposed softwood sample (alternate view)

4.2.3 Results and Calculations

The modulus of elasticity was calculated using the method stated above. A graph is shown for a comparison of the loading and the points of failure. A table of calculated results is also provided.

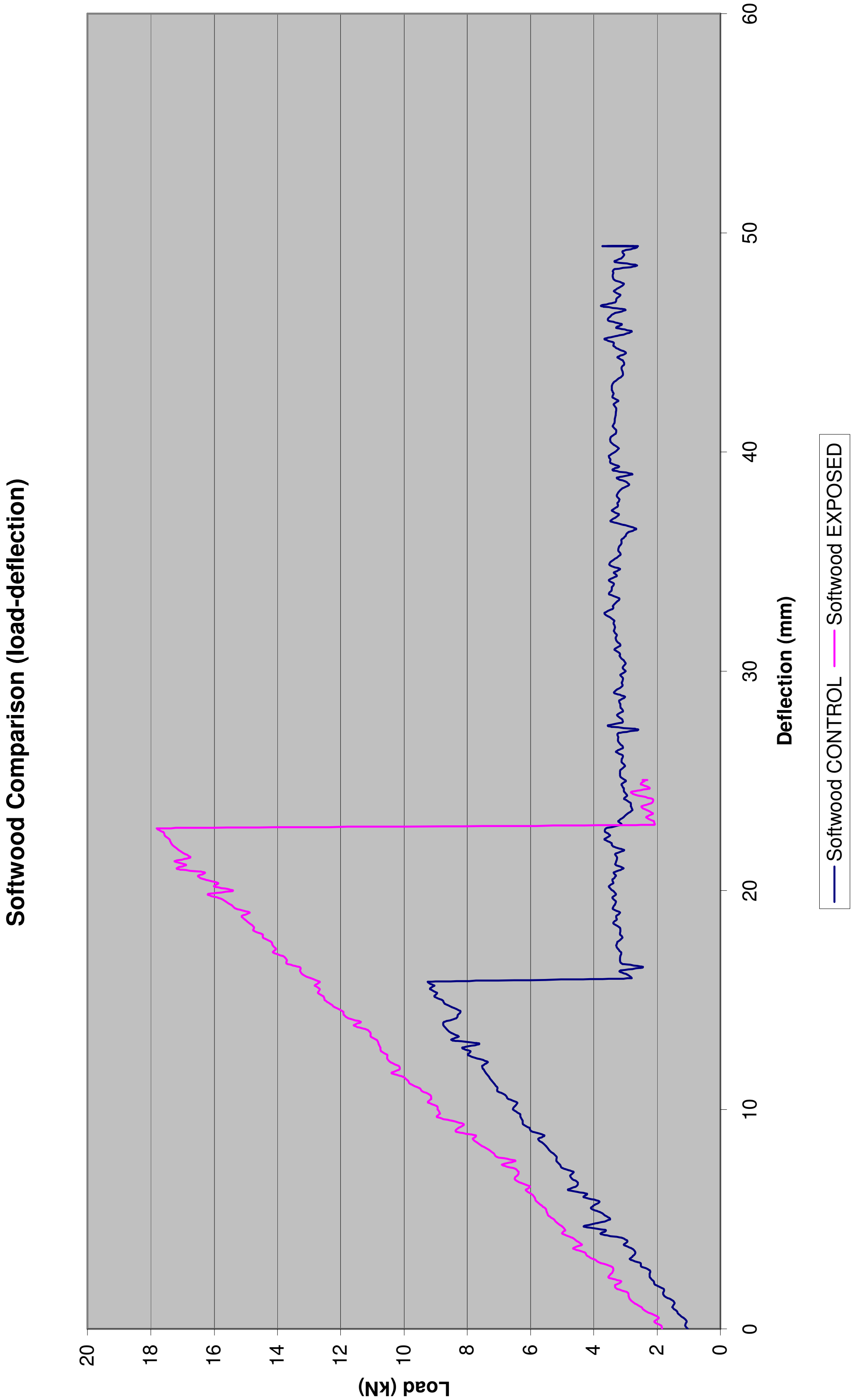

Figure 4.3 Graphical results of softwood testing

	Depth	Width	E
Control	151.1	73.5	6112MPa
Exposed	149.4	75	7872MPa
F7			7900MPa

Table 4.1 Calculated results of softwood testing

It can be seen from the results that only the exposed beam falls within close proximity of its grading strength. A reason why the control beam did not produce a higher modulus could have been because of the large knot imperfection in close proximity of the loading point which caused early failure and weakness in the tension region. This would have reduced the effective cross-sectional properties of the beam, resulting in more deflection from the same load.

There were no noticeable warping effects in either beam. This could be due to the physical size of the cross section resisting warping and internal strains created from the seasoning process.

4.3 Hardwoods

Similar to the softwoods, only two samples of hardwood were tested, which were a control sample and a sample that was exposed. The samples were of F17 grade. The relative modulus of elasticity for F17 graded timber is E = 14,000MPa.

4.3.1 Control Sample

The control beam exhibited an almost perfectly constant load-deflection line until the trade mark tapering of plastic failure. The initial failure within the fibres did not impact the deflection significantly. Instead many steady small failures occurred slowly reducing the load bearing capacity. The test was stopped once the failures had apparently ceased and the bearing load remained constant. After deflecting more than 90mm and after many small failures, the sample held one third of its peak strength.

The effect of the dense cell structure can be seen within the graph <reference>. The lack of sudden failures resulting in reduction of strength fortifies the strong intercellular bonds theory. The main mode of failure present in the control beam was the raw tearing of fibres from tension within the beam, there was very little splintering. An almost vertical line under the loading point along which the fibres failed developed during testing. This reinforces the concept of the strong bonds within the cell structure giving resistance to lateral forces.

4.3.2 Exposed Sample

The exposed sample loaded and deflected similarly to that of the control sample. The exposed sample achieved a higher peak load than that of the control sample. This can be attributed to the seasoning process making the sample more rigid. Once the sample entered the plastic deflection, small failures occurred within the beam. Once again, this can be attributed to the brittle nature of seasoned wood.

The exposed sample generally split and splintered as the small failures occurred. Far less splinters visibly occurred than the softwood samples. The splits that did occur did not propagate along the grain of the samples, but were localised around the loading point.

Figure 4.4 Failure of the exposed hardwood sample

4.3.3 Results and Calculations

The modulus of elasticity was calculated using the method stated above. A graph is shown for a comparison of the loading and the points of failure. A table of calculated results is also provided.

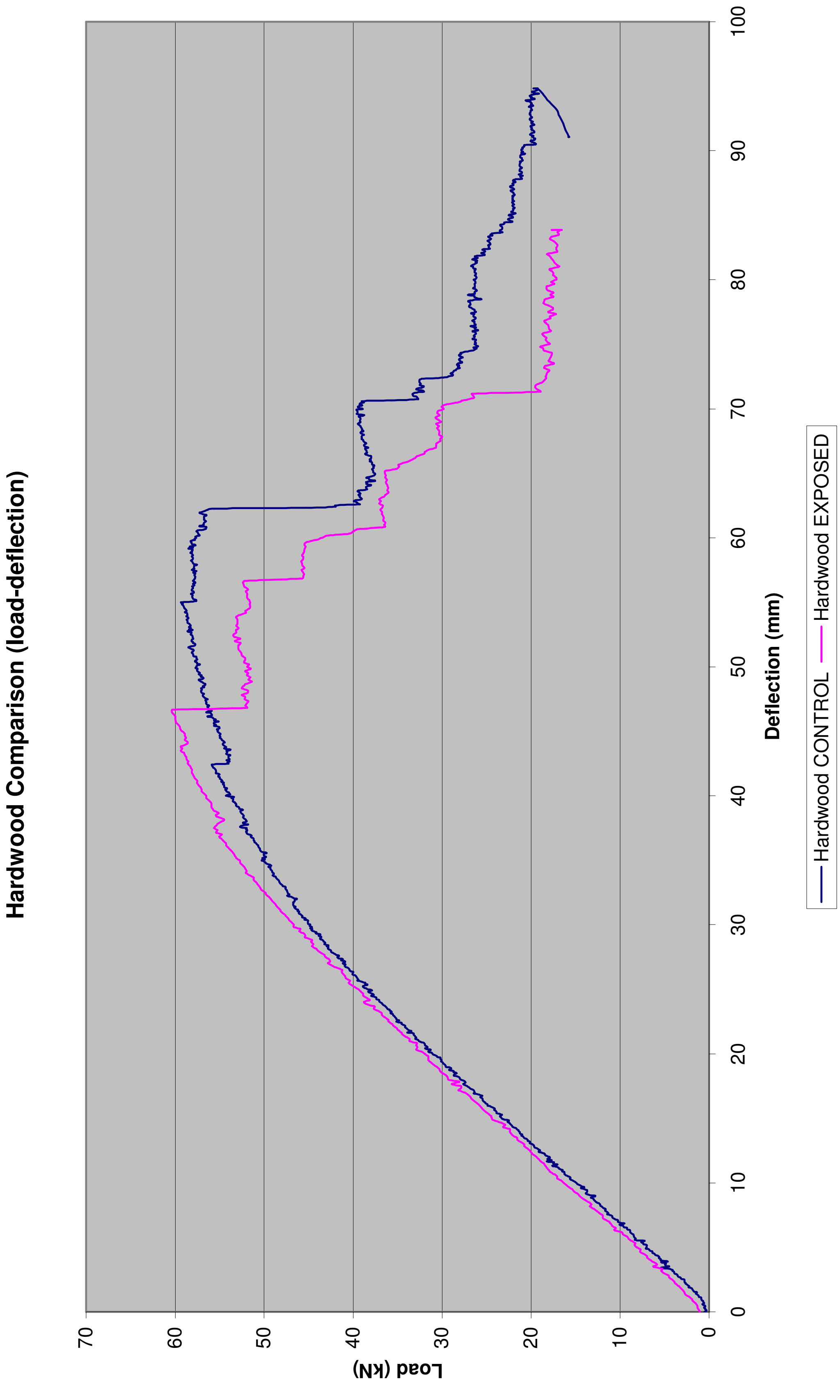

Figure 4.5 Graphical results of hardwood testing

	Depth	Width	E
Control	151.5	73.3	16592MPa
Exposed	149.4	73	17850MPa
F17			14000MPa

Table 4.2 Calculated results of hardwood testing

Both samples exceed the F17 grading for relative modulus of elasticity. It can be seen that the dimensions of the control sample are slightly larger than that of the exposed sample. Assuming both samples came from the same batch, it would show that the control beam has more moisture still contained within the cell structure indicating a less seasoned state than that of the exposed sample.

4.4 GluLam

The GluLam samples tested fall into the GL17 glued lamination timber grading system. As stated by AS 1720.1:1997, GU17 grading has a relative modulus of elasticity of 16,700MPa. There were five samples tested, one control and four exposed. Each of those four samples had different arrangement of paint coatings applied to them.

The timber used in this GluLam product is Tasmanian Oak. Tasmanian Oak is softwood which is very absorbent accepting finishing stains, paints and glues readily. It is also well coloured and grained wood perfect for visual use. Being able to absorb glue deep within its cell structure and having naturally appeasing appearances make is a suitable choice for use in GluLam. However a well seasoned piece of Tasmanian Oak can become very brittle and rigid often shattering if stuck with a strong enough impact.

4.4.1 Control Sample

The control sample began to exhibit elastic loading during the early stages of loading, until an early minor failure. This early failure was caused by a join in the bottom row of laminates. The jointing method used is not strong enough to ensure a good composite action. However, after this failure, a new effective cross section established and began to reload. During this reloading phase, the sample reloaded to 90% of the initial load.

During testing, it was noticed that there was less variation along the curve compared to that of the solid woods. It shows that imperfections in wood sections can be selectively excluded from GluLam beams resulting in a manufactured wood product that is free from imperfections and more uniform throughout. This allows GluLam beams to exhibit pure beam properties. This was shown when the final failure occurred. The stresses caused splitting which propagated through the grains of the sections and through the glue lines.

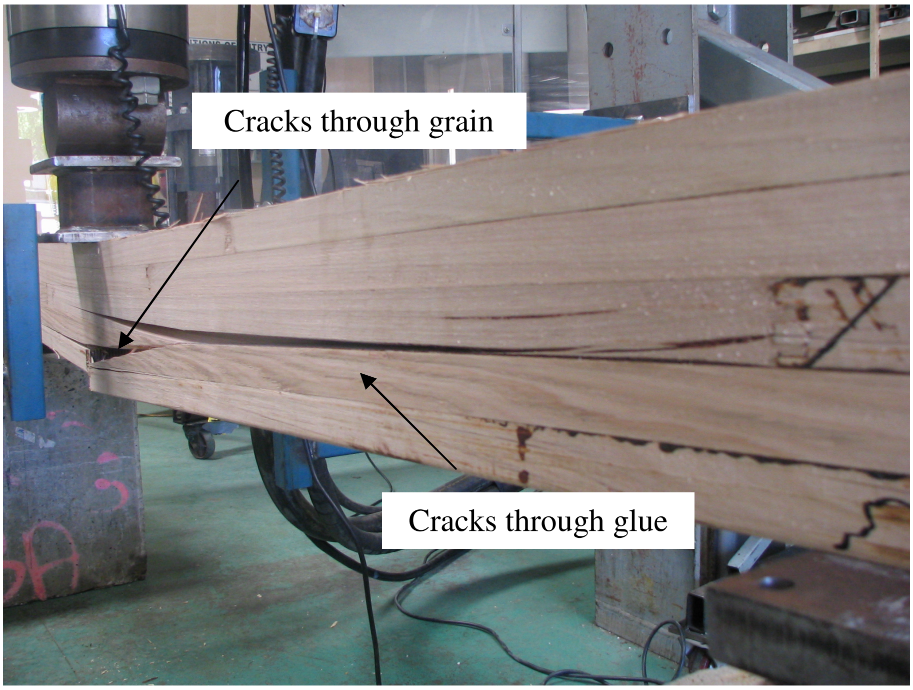

Figure 4.6 Failure of the control GluLam sample

Figure 4.7 Failure of the control GluLam sample (alternate view)

4.4.2 Exposed Sample

The exposed sample loaded elastic through to plastic without failure. Small failures did occur in the plastic stages but these cause a minor reduction in strength. The major failure occurred around 50mm of deflection. The bottom row of laminates failed in a brittle fashion similar to the exposed solid wood samples.

The sample continued to reload itself and fail, each time doing so, the next row of laminates would fail indicated by the slow rises and short falls in the load-deflection graph. Each failure did not result in large scale cracking and splitting, but localised failure of the cellular and adhesive bonds. Some of the failures were so brittle that debris was almost projected from the sample. The brittle, splintering failure can be seen in figures 4.8 and 4.9.

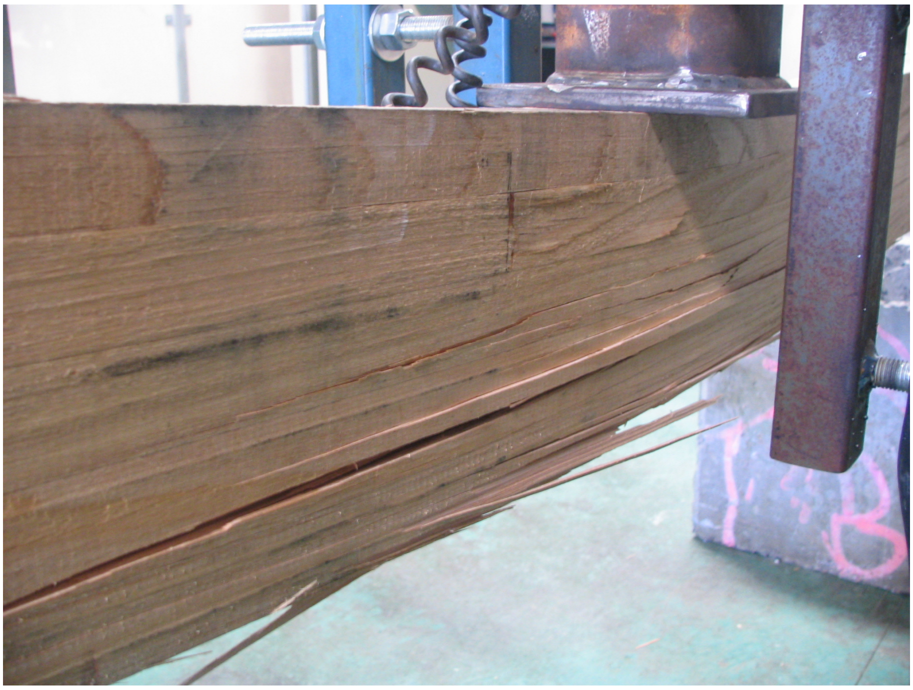

Figure 4.8 Failure of the exposed GluLam sample

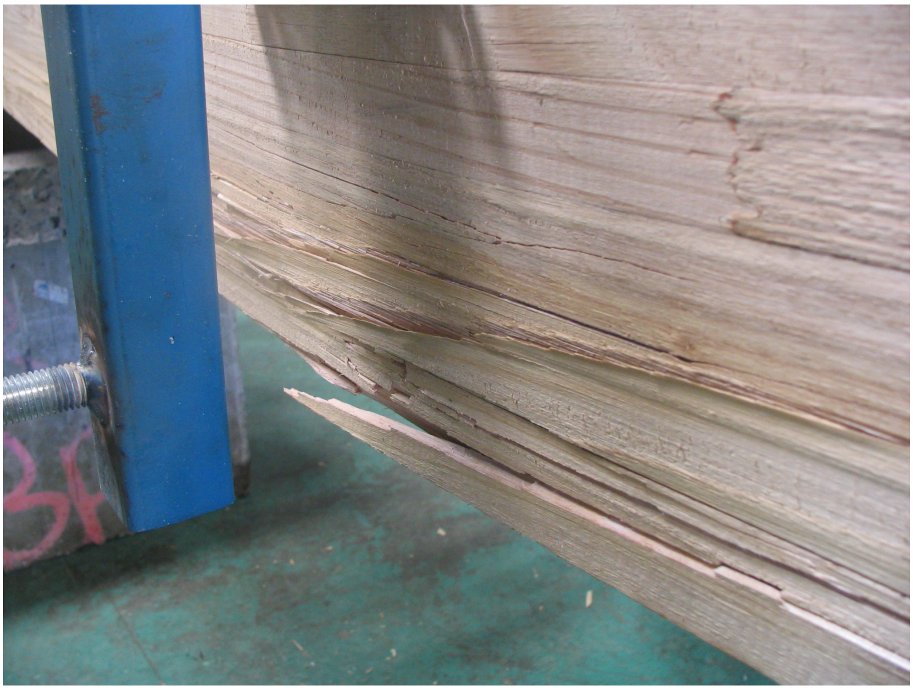

Figure 4.9 Failure of the exposed GluLam sample (alternate view)

4.4.3 OAA GluLam Sample

OAA sample (one coat oil-based primer, two coats acrylic finish) was the sample prepared to the Technical Data Sheet external protection standard provided by Hyne. This protection standard is currently used in industry. This sample reached the highest peak strength of all the GluLam samples tested. The sample's sudden failure, which can be seen in figure <insert number>, resulted in cracks forming instantly and propagating following the glues lines, both horizontally and vertically.

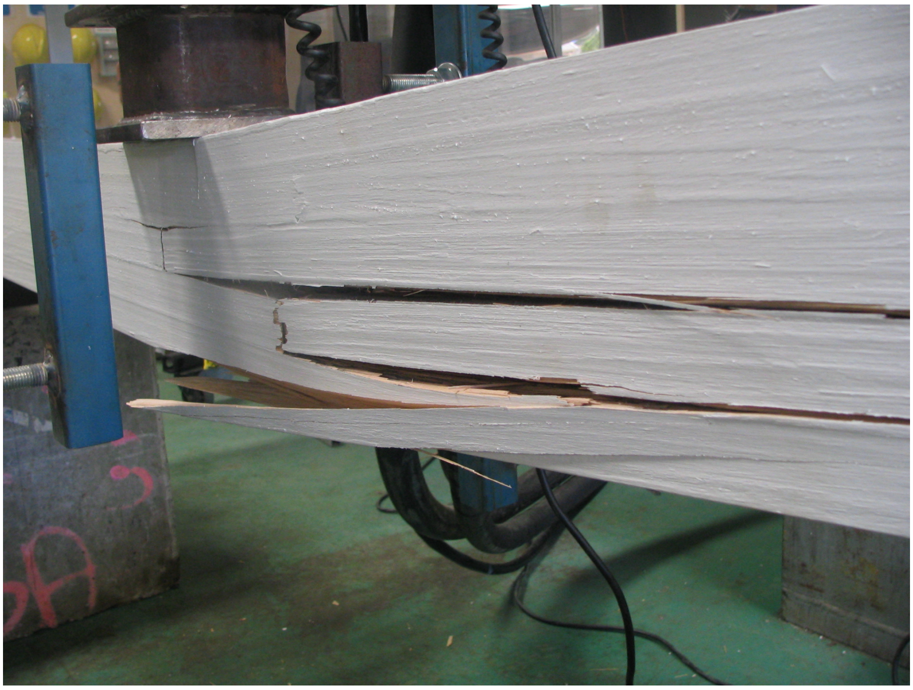

Figure 4.10 Failure of the OAA GluLam sample

4.4.4 O GluLam Sample

The oil based primer sample suffered the same problems as the control sample did. A join in the bottom row of laminates was directly underneath the loading point. This caused an early failure similar to the control sample, which can be seen in the graph.

The sample reloaded to achieve a strength that was almost as high as the first failure before suffering a sudden failure. This failure resulted in massive splitting which propagated through the grains of the timber sections rather than the glues. The splitting managed to spread from the failed join along a semi-shear induced path all the way to one end of the sample, effectively removing a sizable portion of the sample.

Figure 4.11 Failure of the O GluLam sample

Figure 4.12 Failure of the O GluLam sample (alternate view)

4.4.5 A GluLam Sample

This sample was coated in acrylic water based primer only. This sample suffered an early failure similar to the oil based primer sample and the control sample. This early failure was not contributed to joints, but a knot imperfection found in the bottom lamination.

The sample reloaded itself until sudden failure. This sudden failure occurred entirely within the glue lines. Apart from the initial failure, there was no cracked or splintered wood.

Figure 4.13 Failure of the O GluLam sample

4.4.6 Results and Calculations

The modulus of elasticity was calculated using the method stated above. A graph is shown for a comparison of the loading and the points of failure. A table of calculated results is also provided.

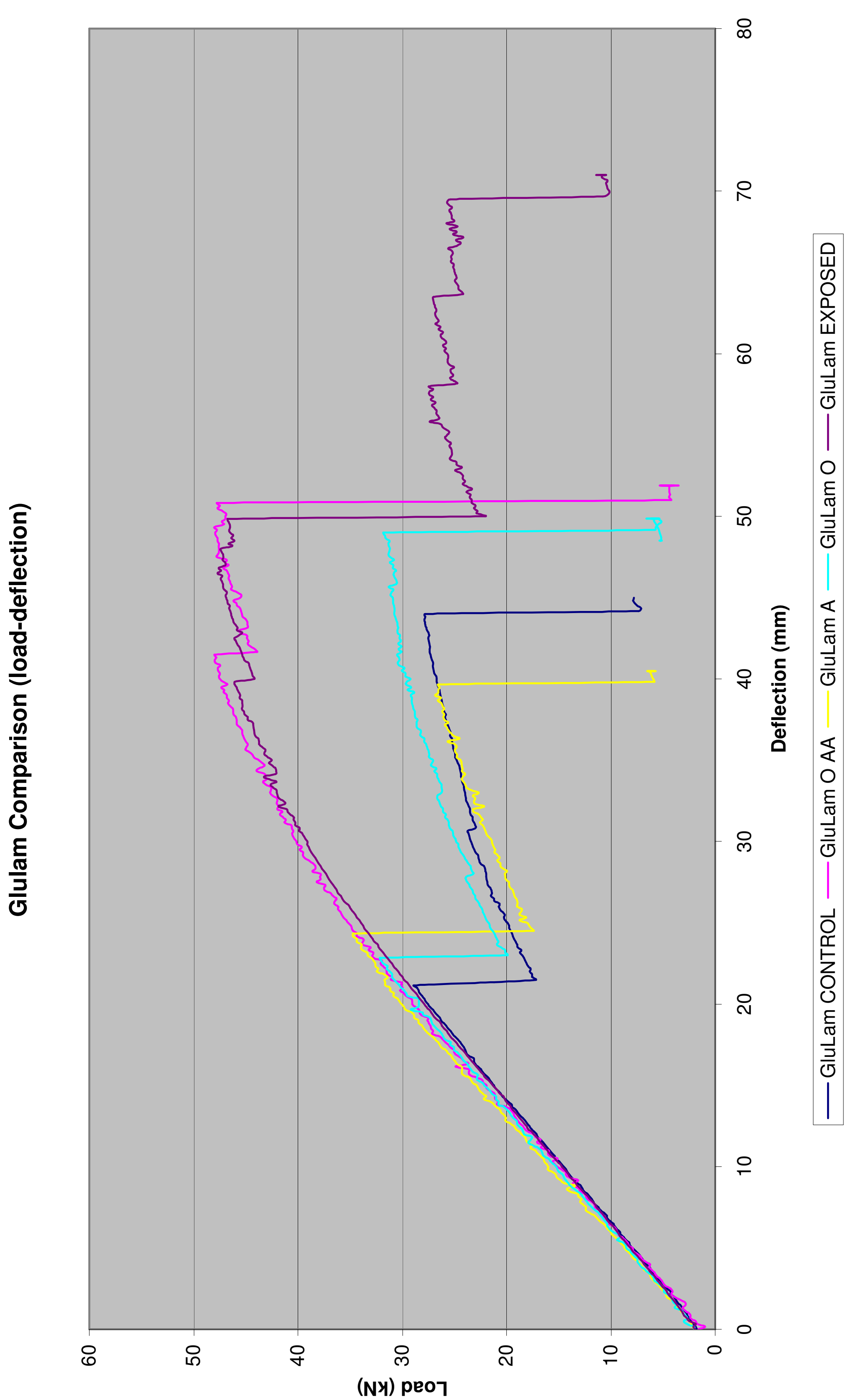

Figure 4.14 Graphical results of GluLam testing

	Depth	Width	E
Control	154.2	65.5	15155MPa
Exposed	153.6	65.5	15409MPa
OAA	154.3	66.6	15969MPa
O	153.1	66.1	15962MPa
A	154	66.4	16219MPa
GU17			16700MPa

Table 4.2 Calculated results of GluLam testing

None of the samples managed to come near there relative grading modulus of elasticity. The control sample had the lowest modulus. This can be attributed to poor placement of the join under the loading point resulting in a reduced effective cross section. Out of the protected samples, the acrylic primer came in at the highest strength. From testing it can be concluded that the acrylic primer coating provides protection for the properties of wood but doesn't protect the properties of the adhesive.

The oil based primer sample and the sample prepared to the technical data sheet standard show similar results. The oil based primer failed in such a way that the oil based primer gave more protection to the adhesive bonds and less protection the wood properties which explain why in the sample the timber split along the grains while the glue lines were relatively unaffected.

The protected samples achieve results higher than the exposed sample which was predicted. Curiously enough, the control beam scored the lowest modulus of elasticity. This can be put down to the initial failure of the join.

4.5 LVL

There were five samples tested. The protective coating arrangements are the same as those used in the GluLam trials. The wood used in these LVL products is radiata pine which is relatively cheap and light when compared to other structural softwoods. From the engineering data sourced from Hyne, the relative modulus of elasticity is E = 13200 MPa.

4.5.1 Control Sample

The load deflection line was generally constant with only slight variations during testing. There is no noticeable plastic deformation until the member suffered a sudden failure. After failure, the sample did not reload. The sample failed by means of vertical cracking in the tension region. The makeup of the beam prevented any splits from propagating. This is due to the sandwiched 3.2mm veneer being sufficiently thin to transfer the load through the adjacent bond rather than supporting load through the single veneer. This shows good composite action within LVL as all the elements are equally loaded and deflected.

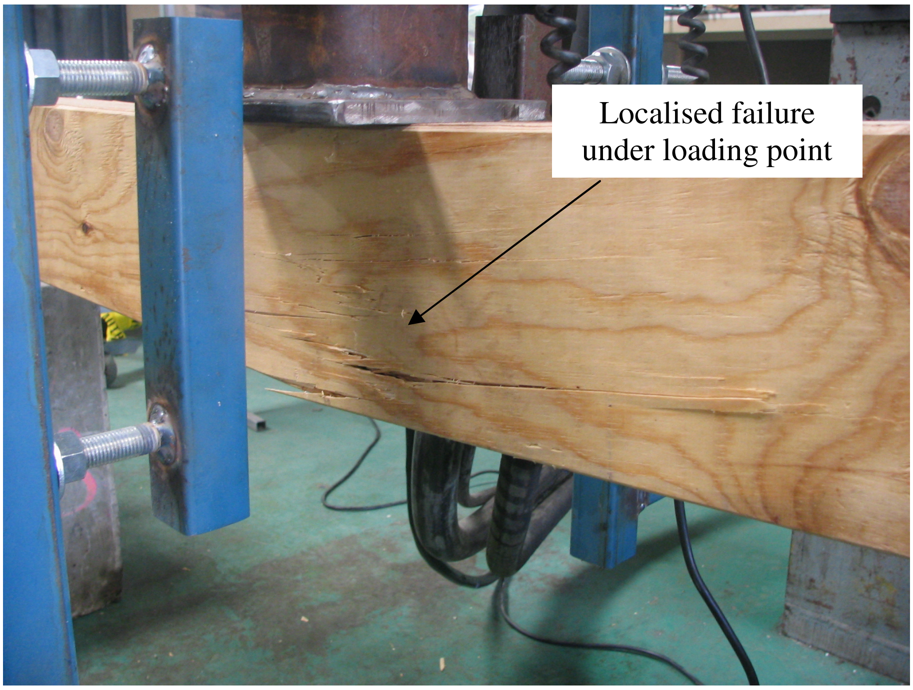

Figure 4.15 Failure of the control LVL sample

4.5.2 Exposed Sample

The exposed sample loaded and failed in similar fashion to the control sample. There is a noticeable change in the slope of the curve indicating some plastic deformation. When the sample failed, the cracking of the sample was not localised by spread slightly through, which appears to be areas of common weakness in the veneers. Two main cracks formed travelling through the sample from one side of the sample to the other, indicating these cracks were not localised to singular veneers. This brittle like propagation of cracks can be attributed to the seasoning process which this sample was exposed to while out in the environment. Once again, a good composite action was achieved between the veneers.

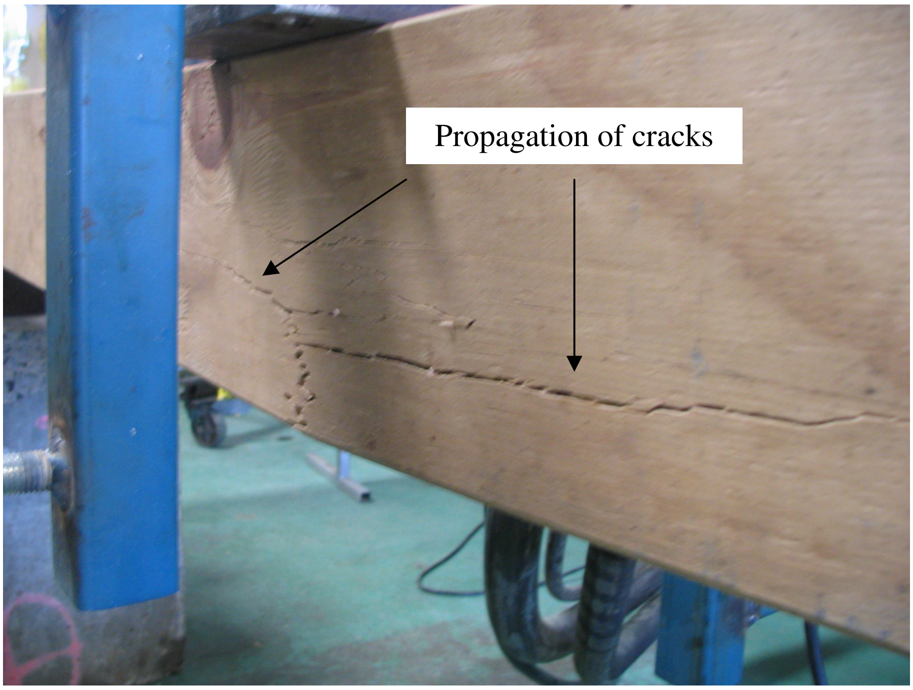

Figure 4.16 Failure of the exposed LVL sample

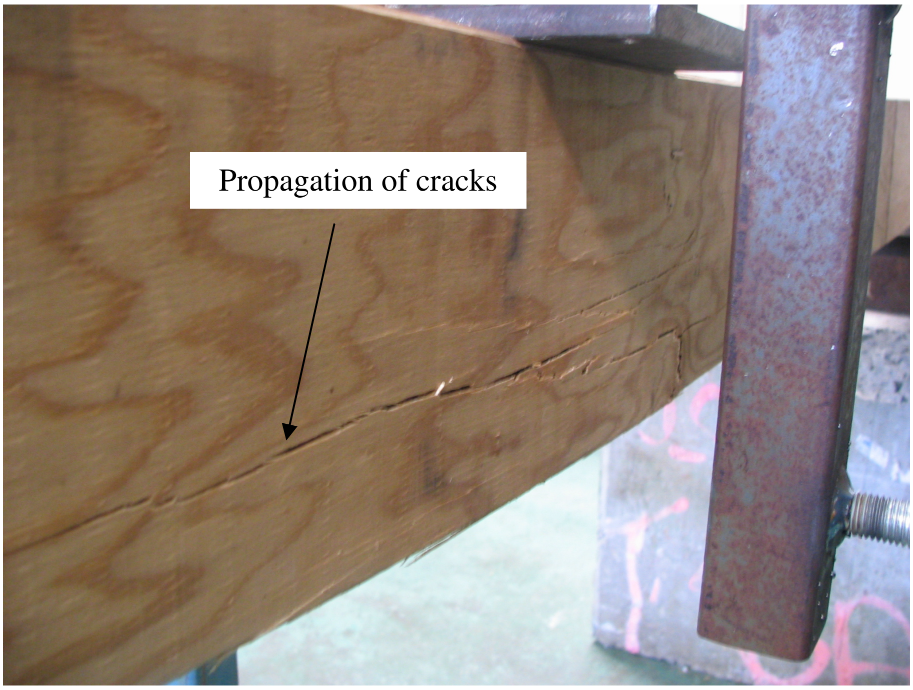

Figure 4.17 Failure of the exposed LVL sample (alternate view)

4.5.3 OAA LVL sample

As predicted the sample coated in one coat of oil based primer and two coats of acrylic finish loaded similarly to that of the other samples. This sample reached the highest peak load of all the LVL samples tested. The tapering of the load-deflection curve indicates the sample had some plastic deformation before failing. The white exterior allowed made any cracking visible.

The OAA sample failed by localised cracking. There were not major concentrations of cracks like in the exposed sample. The cracks were evenly dispersed through the veneers and where individual to each veneer with no shared pattern. No strength was retained after the initial failure indicating composite beam action.

Figure 4.18 Failure of the OAA LVL sample

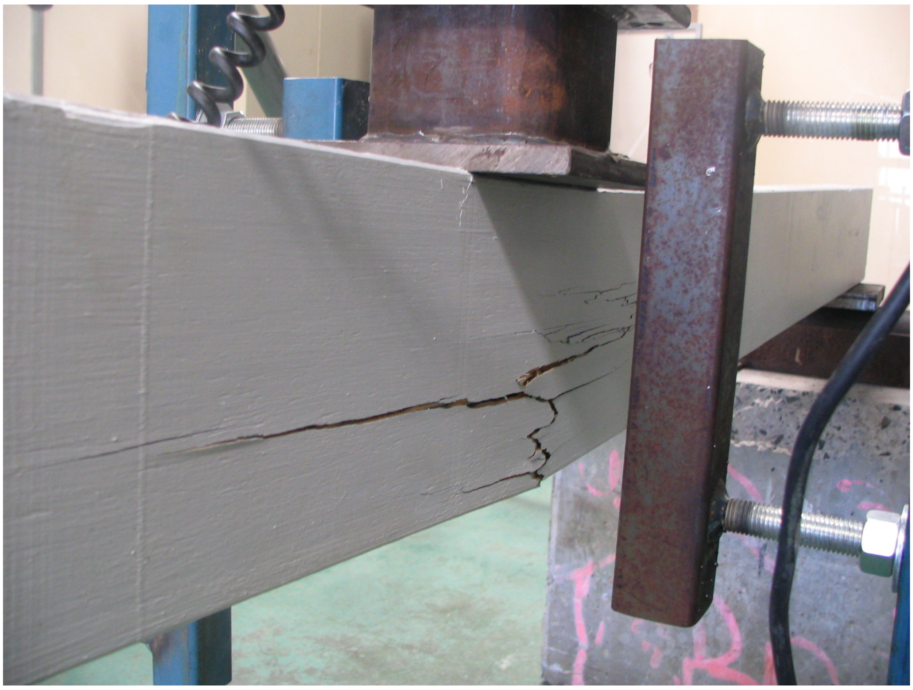

Figure 4.19 Failure of the OAA LVL sample (alternate view)

4.5.4 O LVL Sample

A consistent trend was beginning to emerge with the loading pattern of the LVL samples. This sample was slightly different in which the plastic deformation began earlier in the testing. The mode failure indicates that the wood veneers were the weak link. Large cracks occurred that carried through the bonds of the sample. Like in the GluLam samples, the oil based coating would appear to preserve the strength of bonds more so than the wood strength.

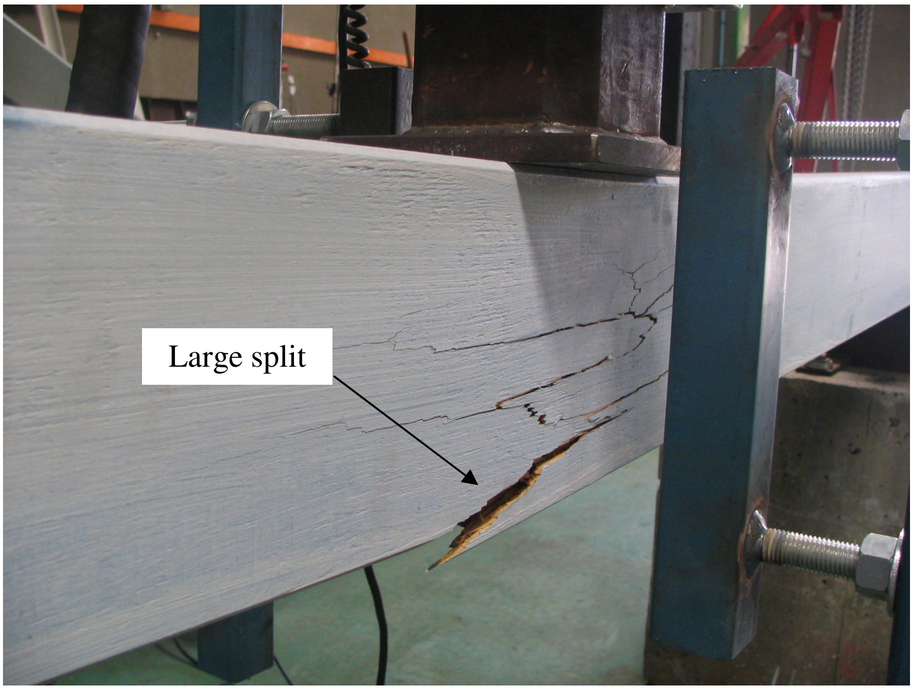

Figure 4.20 Failure of the O LVL sample

4.5.5 A LVL Sample

The acrylic primer coated sample loaded a little differently to the other samples tested. The initial loading was less than that of the other LVL samples. The sample did not portray plastic deformation until it was close to failure. This sample failed such that the cracks and splits that formed were individual of each veneer, ei. each veneer cracked in a slightly different position to its neighbours. This shows that acrylic primer protects the structural properties of wood but does not preserve the strength of the adhesive bonds.

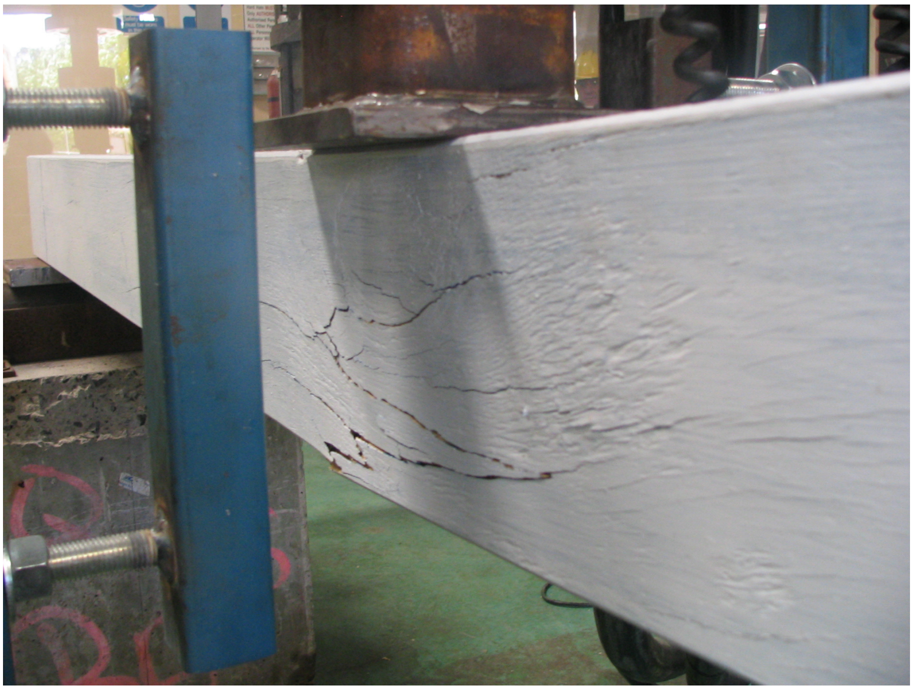

Figure 4.21 Failure of the A LVL sample

4.5.6 Results and Calculations

The modulus of elasticity was calculated using the method stated above. A graph is shown for a comparison of the loading and the points of failure. A table of calculated results is also provided.

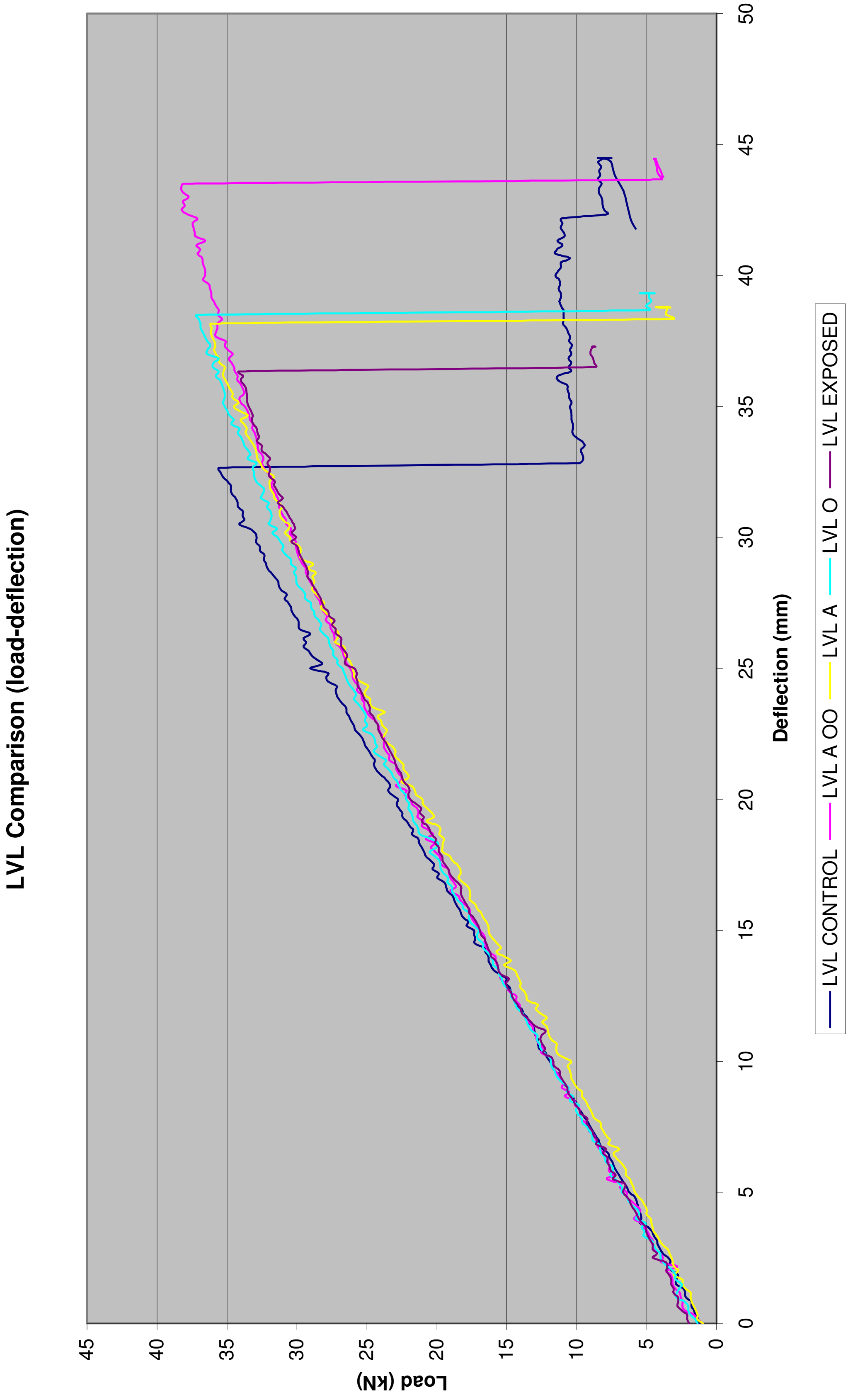

Figure 4.22 Graphical results of LVL testing

	Depth	Width	E
Control	150.7	63.1	14157MPa
Exposed	151.7	65.2	12199MPa
OAA	150.8	66.3	12504MPa
O	153.5	67.4	11849MPa
A	150.5	65.4	12760MPa
Specification			13200MPa

Table 4.3 Calculated results of LVL testing

It can be seen from the results table that there is little similarity between any of the samples modulus of elasticity. The control sample ranked highest and was the only sample that exceeded specification values. The acrylic coated sample had the highest modulus of all the protected samples, while the oil based primer ranked lowest out of all the LVL samples. The acrylic coat seems to protect wood properties while the oil based protects the adhesive properties. This shows that LVL inherent weakness is within the thin veneers. As the veneers are so thin, should then become seasoned, they will become very brittle and the fibres may shrink and separate on a microscopic level.

4.6 I-Beam

There is no available engineering design data available for the I-Beam products tested, only span tables for size selection. The aims of testing these samples were to see the modes of failure and a comparison of peak loads and deflections.

4.6.1 Control Sample

The I-beam samples loaded similarly to that of the LVL. Loading began as elastic and the curve tapered slightly indicating some plastic deformation. The sample then failed suddenly. Upon inspection, it was found that the glue bonds between the bottom flange and the web had separated effectively loosing any composite action. Neither flange showed signs of failure or damage. Shear damage was visible in the web indicated by an angled crack. A peak load of 25kN at 22.8mm deflection was recorded.

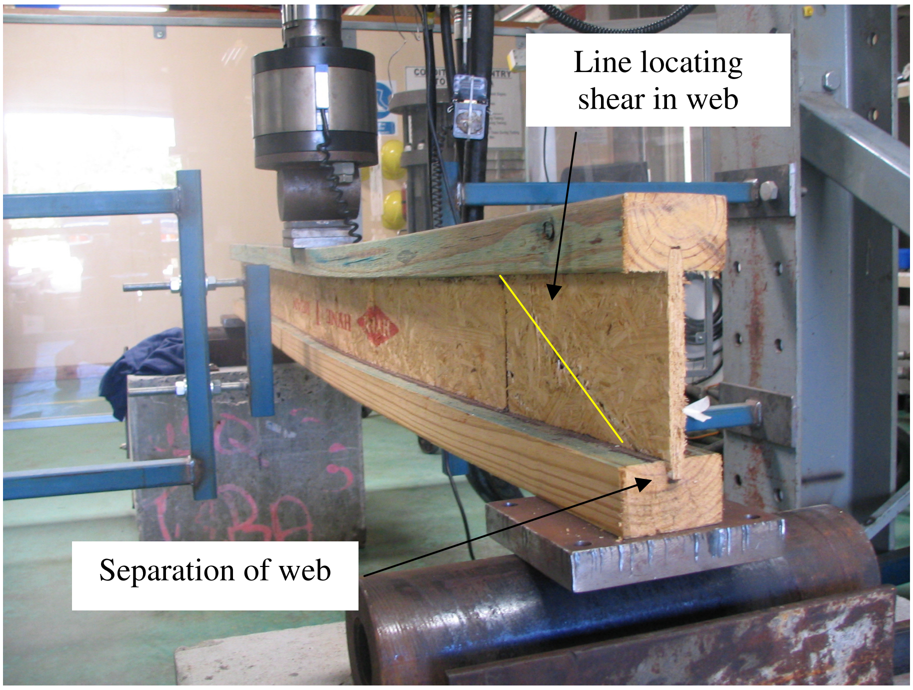

Figure 4.23 Failure of the control I-Beam sample

4.6.2 Exposed Sample

It was predicted that the failure in the exposed sample would occur where the web meets the flange again as this product is not designed for outdoor exposure and the glues would weaken in such conditions. The load-deflection curve is similar to that of the control sample with a few exceptions. The plastic deformation region is more defined within the curve and the sample reaches is peak load at a deflection less than that of the control sample.

The sample failed in the same region as the control sample. The web separated from the bottom flange. No shear effects were present in the web. The flanges were undamaged. A peak load of 25.5kN was achieved at 21mm deflection.

4.6.3 Conclusions

It can be concluded that the bonds derives the I-beam's strength. The shear stresses in the bonds caused by the deflection are too great for the adhesives. It can be seen how the natural climate and weather affects the properties of the bonds. The bonds become more rigid and brittle reaching their peak strength earlier than that of protected bonds. A load-deflection graph is provided below.

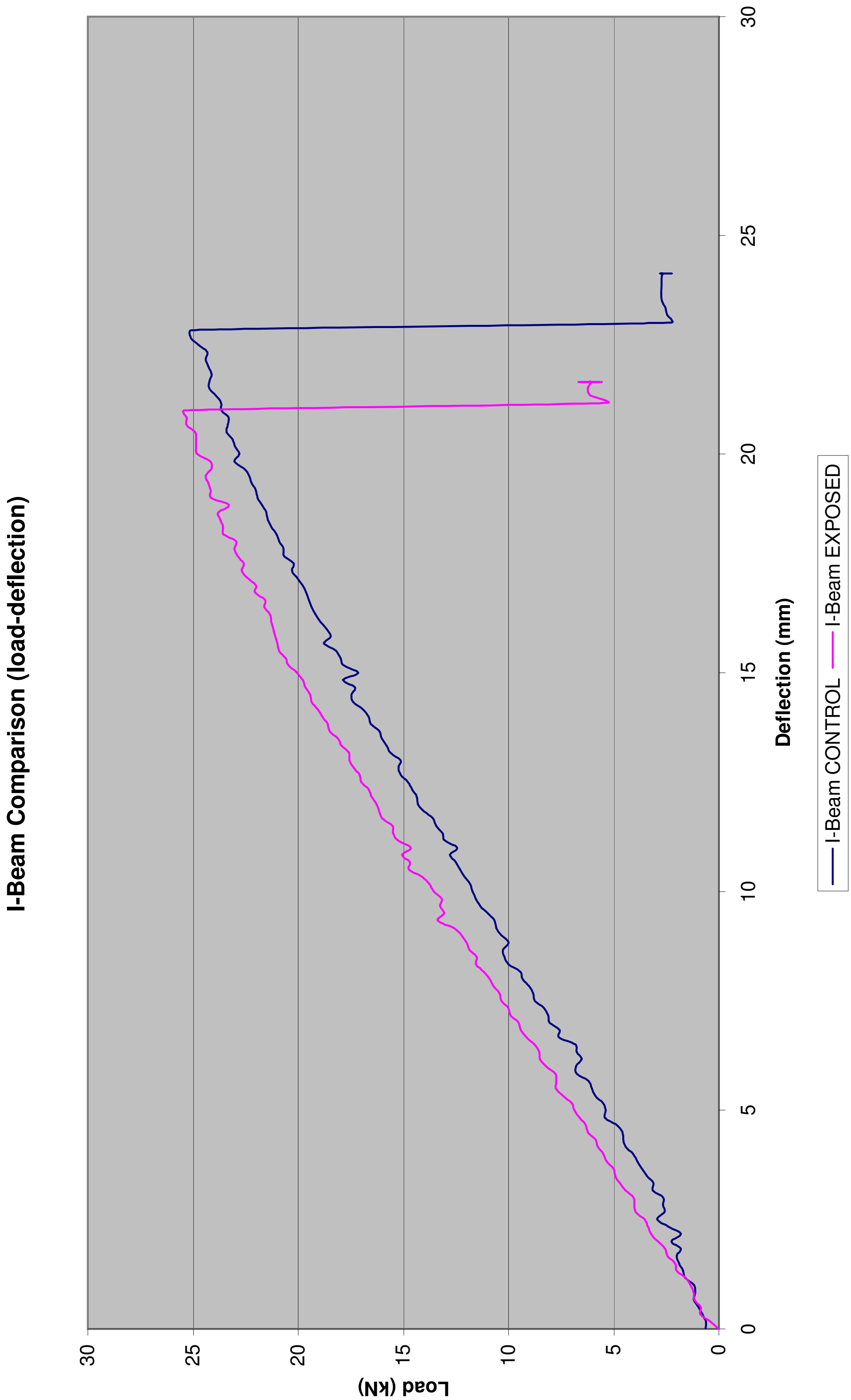

Figure 4.24 Graphical results of I-Beam testing

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

This project has looked at the effect of natural elements on manufactured wood products and solid wood products. Several interesting results will be concluded on and any recommendations to this project will be suggested.

5.1.1 Adhesives and Glues

From testing it can be seen that the glues, resins and adhesives used will naturally degrade over time if left exposed to cyclic temperature change, humidity, UV light and rain. In some manufactured wood products this can be critical as the strength of the design is derived from the bond strength. These products are not for exposed use which is stated by the manufacturer.

The current glues used have elements that are soluble in water which is why they are susceptible to the effects of weather. Further development of the resins to improve resistance to degradation would be beneficial for strength.

This may have a negative impact on costs of construction and installation as glues and resins that resist degradation are often expensive to obtain and dangerous to handle and use.

5.1.2 The Effectiveness of Protection

From testing, it can be seen that different protective paint types protect specific properties. It was found that oil based primer protects bonds while acrylic protects timber. Timber does not absorb oil based products as readily as water based and this would have caused the oil based primer to adhere and cure to the glues better than the timber. The opposite occurs with the water based acrylic paint. It is more readily absorbed by the wood and repelled by glues and resins. A combination of oil based and acrylic paints need to used to ensure design strength of manufactured wood products.

This proved that from the coating options tested in this project, there was no arrangement that could better the one specified in the technical data sheet. As it stands, no recommendations can be made to alternative protective arrangements.

5.2 Recommendations

It can be seen in some of the results from testing some results were not as expected. This could have been for a number or reasons. The sample may have been faulty or damaged, the paint may not have fully sealed the timber or the products were made from different batches of glue or timber. Due to the budget constraints on this project, only one sample of each product and coating could be tested. To improve results, more samples could be tested and an average taken. This would yield more realistic results.

Many of the results did not deviate. To rectify this, the samples could be exposed for a longer period. This would hopefully vary results between the different samples and fortify any advantages and disadvantages.

5.3 Final Words

The local residential housing industry is still on the rise. Cost effective methods of design are being developed all the time. There are many opportunities for research in this field.

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Australian Standards, AS/NZS 4266.5:2004 Reconstituted wood-based panels – Methods of test – Modulus of elasticity in bending and bending strength

Span tables for residential building 2004, Carter Holt Wood Products Australia Pty Limited

Hyne and Son Pty Limited, Hyne Timber, <www.hyne.com.au>

APPENDIX A

University of Southern Queensland
Faculty of Engineering and Surveying

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Aaron John NEUBAUER**
TOPIC: Testing of current flooring systems and materials
SUPERVISORS: Dr Thiru Arivanthan
Dr Santhi Santhikumar

PROJECT AIM: This project aims to test and compare the beam components in residential flooring design, with the products tested ranging from conventional wood bearers through to composite LVL and ply based I-beams. The effects of the environment and methods of protection will also be tested.

PROGRAMME: Issue B, 28th August 2006

1. Select a product for each of the beam categories (softwood, hardwood, LVL, GLULAM, composite shape) subject to availability.

2. Research theories, standards, BCA and any other literature related to the beam materials chosen. Research common uses of beams in residential construction and methods/standards of environmental protection.

3. Prepare samples from each category with various protection types, deemed suitable for this project. Exposed all the samples to all aspects of weather and the environment (ei. leave outside) for a suitable duration so that any possible effect on the samples is significantly shown in testing.

4. Test each type of beam and compare the effectiveness of the protection types applied to the members. Tests include the beam test. Any other effects, such as warping and size variation, should be noted and compared upon.

5. Evaluate the results from the beam tests.

6. Draw conclusions from the test results, comparing with product literature and Australian Standards, and make recommendations on any effects on the products and the effectiveness of various protection methods used.

AGREED:

__________________________(Student) __________________________(Supervisors)

__/__/____ __/__/____