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Advanced research into floor performance issues Sub project: The interaction between adhesives, flooring profile design and floor performance

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Advanced research into floor performance issues Sub project – The interaction between adhesives, flooring profile design and floor performance

Prepared for

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1.0 Introduction

It is evident that in the marketplace there are a wide range of hardwood flooring profiles in addition to the standard profiles complying with AS 2796 – Timber – Hardwood – Sawn and milled products. Many of these profile variations relate to overlay flooring but even with the common 80 x 19 and 130 x 19 mm profiles covered by AS 2796 there are also many subtle variations. Performance issues relating to the interaction between fixing method and profile design have only been touched on previously with some aspects highlighted in a previous FWPRDC research project (refer FWPRDC Project PN 03.2104).

The trend to date appears to be that flooring profiles are manufactured without specific consideration of the fixing method and similarly what is important from an adhesive viewpoint is simply that the product will adhere the timber flooring to a range of substrates. As such no recognition is taken of the interaction between flooring profile, the adhesive properties and the overall performance of the floor.

This project investigated some of these areas by analysing various profile and fixing combinations through conditioning chamber trials and mathematical modeling through finite element analysis. The mathematical modeling using Finite Element Analysis (FEA) was undertaken by Ransi Devendra of Uroxsys Ltd in New Zealand and his two specific reports accompany this report.

This report discusses current profile designs, current adhesives and performance aspects with adhesive and mechanically fixed floors that have been observed in the marketplace. While the necessary role that adhesives play in floor fixing is recognized, particularly with overlay and wider board fixing the additional restraint provided by the adhesive may be contributing to some peaking that is being experienced. Variability in adhesive performance between installations is known and reasons for floor failures that incorporate adhesives have often not been determined. Regarding board profiles there is a vast array on the market. This included many board profiles well outside the bounds of traditional T&G flooring and many different groove arrangements in the lower surface of the boards. It is these aspects relating to both adhesive and profile that the report investigates.

Based on these investigations a series of environment chamber trials were undertaken to evaluate the interaction of a range of flooring profiles and lower surface groove patterns with adhesive and mechanical fixing. The movement and cupped appearance associated with the test panels under differing environmental conditions in the chamber was researched for a range of adhesives, some of which were flexible in nature and others that were more rigid. The methodology, results and conclusion of this work are provided in this report.

Finally the report will assess the chamber trial and finite element work to enable a greater understanding of the interaction of adhesives and profile design. Outcomes from Ransi Devendra's report will be referred to in this section, however it is considered necessary that his reports be studied in order to gain an in depth knowledge of the interactions. It was clear that the chamber trials have highlighted the individuality and variability that is present in timber flooring. The issue is that due to this, some concepts and trends are often not obvious. The great benefit of the

FEA work was that the effects of changing certain parameters could be studied with the natural variability removed and as such significantly enhances the outcomes. From the combined outcomes from these two areas of work principals can be developed that need to be considered to optimise profile design particularly with floors that are adhesive fixed to a sub-floor.

2.0 Marketplace issues

Previous FWPRDC research identified that profile design can have a marked influence on floor performance in an expanding floor, resulting in peaking at board edges throughout the floor. While the testing focused on top nailing into joists it was also apparent that peaking in overlay on sheet sub-floors occurred.

Concerning peaking induced from undercut profiles, there are now a number of installers particularly in South East Queensland and also Sydney who consider this to be of significant concern to them. It would appear that some bamboo flooring is particularly prone to this problem. Bamboo with a thickness of say 12 mm and a 4 mm thick upper shoulder has been observed to have an undercut in excess of 1 mm. We are also aware that some product, particularly if manufactured for the European market, is entering Australia with moisture contents in the range from about 7% to 9%. There have been instances where moisture uptake to say 11% is considered to have resulted in peaking throughout the floor. An example with associated data is provided below in Photos 1 & 2 and Table 1.

Photo 1 – Bamboo profile showing undercut present

Table 1 – Bamboo Flooring Cover Widths & MCs

Board	Cover width	Oven Dry Moisture Content
1 Section	96.3 mm	9.5 %
2 Section	96.4 mm	9.8 %
2 Top half	-	9.3 %
2 Btm half	-	9.8 %
3 Section	Shoulder broken	11.1 %
4 Section	96.2 mm	10.9 %
5 Section	96.1 mm	11.0 %
5 Top half	-	10.7 %
5 Btm half	-	10.9 %

Photo 2 – Peaking in Bamboo Flooring

Based on a cover width of 96 mm, the values in the table are indicative of both an increase in moisture content and cover width. Although slab moisture meters are not necessarily to be relied on, the meter used did not indicate high slab moisture content. The upper to lower half differences in oven dry moisture content are also minimal which is consistent with no moisture issues from the slab nor a moisture induced gradient from which cupping could develop. We are also aware of a similar floor where oven dry testing of samples from within the floor was undertaken, a concrete moisture meter was used and comparable results were obtained. In this later case a sample of un-laid bamboo had an oven dry moisture content of 8%.

Although the peaking is quite evident in bamboo, an inspection of a 130 mm wide Blackbutt floor on battens over concrete also indicated a similar appearance. The details of this are provided in Photos 3 to 5, Figure 1 and Table 2.

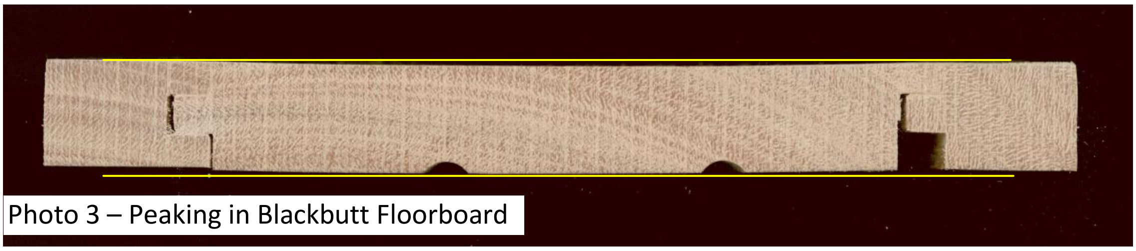


Photo 3 – Peaking in Blackbutt Floorboard

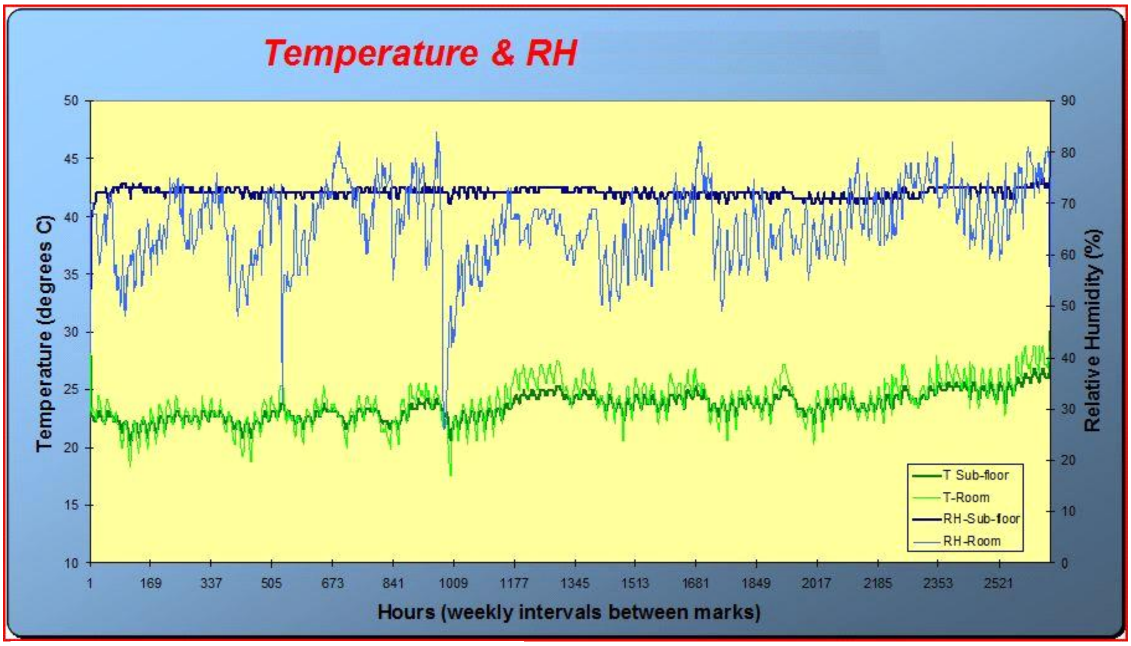


Figure 1 – Room and sub-floor conditions

Table 2 – Blackbutt Floor Cover Width & MC

Board	Oven dry MC	Cover Width
Cross section	11.7%	130.1 mm
Upper Case	11.7%	-
Core	11.8%	-
Lower Case	11.5%	-

Photo 5– Peaking in Blackbutt Flooring

Again there is no moisture gradient through the boards and in this case a data logger was placed beneath the floor for approximately 3 months. It indicated stable relative humidity beneath the floor and variable above the floor. On average the relative humidity during the period was a little higher beneath the floor but there were times where the relative humidity above the floor was greater.

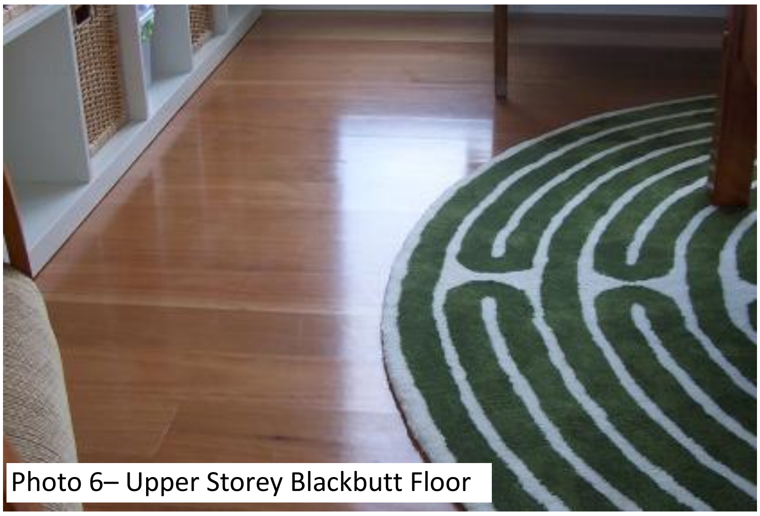


Photo 6– Upper Storey Blackbutt Floor

It is of interest that the upper storey floor which you would expect to be a little drier than the lower storey and less prone to expansion does not show any of peaking present in the lower storey floor (refer to photo 6).

Thin overlay floors are commonly fixed with adhesive and depending on the product, mechanically and adhesive fixed. Such products are not suitable for structural floor and therefore use of adhesives with these products is the norm. The cupped appearance after installation has been a concern to many in the industry. One example of such a floor is shown in photos 7 and 8.

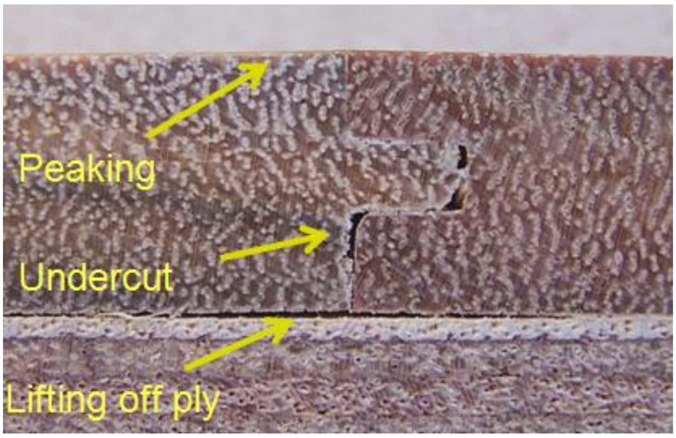


Photo 7 & 8 – The appearance of the floor a close up view of the peaking present in the floor.

During the course of the project the occurrence of peaking floors has been considerable and not limited to a particular product type. Solid timber flooring of various widths and thicknesses, prefinished flooring and related products such as bamboo all have examples where peaking has occurred. In most instances adhesive has also been used in the installations.

Although similar examples have been reported, these three examples have been investigated more thoroughly. However, with peaking occurring in some floors and not other similar floors, the question often remains why this floor and not that one.

The initial trials that investigated the effect of undercut related to timber flooring on joists and in the chamber environment moisture uptake on upper and lower surfaces of the flooring would have been relatively even. However, when a floor is laid over particleboard or plywood, on battens or directly to a slab the conditions beneath the floor are likely to differ significantly from the conditions above the floor. As such with rising relative humidity there is likely to be preferential moisture uptake into the upper surface of the boards. Due to this peaking may still be possible when there is minimal undercut and some have reported this with overlay flooring in moister environments.

The previous FWPRDC study also identified that adhesives restrict the amount of expansion that occurs in a floor compared to mechanical fixing. However, it did not identify this movement in comparison to the unrestrained movement of the boards. An opportunity became available to investigate this and the results indicated that in panels of nine 130 mm wide Spotted Gum boards the unrestrained expansion was approximately18 mm, nailed with 50 x 2.5 T head nails on joists about 9 mm and with a full bed of adhesive on ply with some mechanical fixing about 6 mm. Hence this suggests that the fixing system including nailing provides considerable restraint even in high density hardwoods.

However the question must be asked whether the adhesive, which will primarily restrict the bottom of the board from moving is causing higher pressures in the top shoulders of the boards, particularly with preferential moisture uptake from moist air above the floor. As such the swelling of the top surface of the boards combined with restricted movement may also be contributing to peaking. In contrast to this many sports floors rely on mechanical fixing only, and with expansion allowance every 10 or so boards, they are freer to move. It is of interest that we have not observed peaking issues with these floors.

In addition to peaking there are many instances of floors cupping and buckling off substrates when adhesive fixed. Although, this is often the result of external moisture, the bond between the timber flooring and substrate is often not as strong as expected. Although the floor may appear satisfactory after initial sanding and finishing, under environmental conditions that induce swelling, buckling can eventuate. In many cases this type of issue is attributed to poor substrate preparation or insufficient contact between the timber flooring and adhesive during the curing period of the adhesive. Nevertheless, it is a prevalent marketplace issue.

The market also provides examples of issues that are not easy to comprehend. One example relates to a floor laid over a particleboard sub-floor where the particleboard was prepared in the same manner throughout and completely sanded. However in this job half the floor was fixed with one polyurethane flooring adhesive and the other half with a different polyurethane flooring adhesive. In this case one adhesive stuck so well that when boards were removed part of the sub-floor also lifted and was very difficult to lift, yet with the other adhesive boards lifted with relative ease (refer photos 9 & 10).

Photo 9 – High bond strength

Photo 10 – low bond strength

Photo 11 – adhesive peeling from board

In Photo 11 we also have the situation where the adhesive can simply be peeled from the back of the board. This is also an example of an issue that is difficult to comprehend.

Some failures, relating to a lack of adhesion are more easily understood, however, they too require considerable investigations. Two examples of this are provided below. In the first example the parquetry floor laid with a polyurethane flooring adhesive buckled and lifted in only one room of a number in which the floor was laid. On viewing the underside of the block (refer Photo 12) it was evident that the adhesive was still sticky and had not cured. The cause of this was determined to be that the 'brickies' had spilt a drum of brick cleaning chemical on the slab. At the time of floor installation this previous spill was not observable. Similarly, in another parquetry floor also laid with a polyurethane flooring adhesive there was a lack of adhesion throughout much of the floor. In this instance a temporary slab sealer had been applied to the slab and again although there was no evidence of it at the time of installation, it resulted in a substantial failure.

Photo 12 – Effect of cleaning product spill on slab Photo 13 – Effect of sealer for slab curing

It should be emphasized that with each of these examples it is unlikely that there is an issue with the adhesives, however for one reason or another each floor has failed. This also highlights that the flooring and the fixing cannot be viewed in isolation from each other. The flooring profile is important, the method of fixing is important and although both flooring and adhesive can be deemed to meet their respective manufacturing requirements, this is of no practical significance if the resulting system fails. It is therefore only by evaluating the combined systems that such performance issues will be overcome.

Photo 14 – Testing the uplift force associated with an expanding adhesive and staple fixed Spotted Gum floor.

In the previous FWPA flooring research project some testing was undertaken to determine the vertical forces when an adhesive and mechanically Spotted Gum fixed floor to plywood expands. The purpose of this was to determine the suitability of fixings into slabs. With reference to Photo 14 it is evident once flooring is bonded to a sub-floor such as plywood then in effect and engineered product the width of the sheet is being created. With no expansion no vertical forces are generated. However, with an increase in moisture content of say 4% the force to flatten a 2400 x 1200 sheet would have needed to be about 1.7 tonne. Clearly, the higher the density of the timber the greater the force. Early in 2008, Brisbane experienced an extended period of more frequent rain and during this time the swelling pressure and uplift force was sufficient to separate the sub-floor (both plywood and particleboard) from the joists. Similarly, timber floors are being adhesive fixed over tiles and there are instances the tile bond to the slab failing due to the uplift forces generated. This is again illustrates the need for the effects of the complete system to be evaluated.

Also associated with adhesives we are seeing direct fixing to slabs becoming a more common practice and this is particularly so in Western Australia where the practice is well established. Pre-finished flooring of both Australian and non-Australian species are also becoming more prominent in the market. With direct fix the use of applied moisture vapour barriers as a system to be used with the adhesive is being promoted and taken up by the industry. Consequently, some mixed systems are also being used. These practices either as a single or mixed system is also provided another avenue where floor failures are occurring where adhesion between the adhesive and moisture barrier is parting and again the contributing factors are not well understood. Photos 15 &16 below provide two examples of prefinished floors that have lifted from the slab, one a non-Australian species Western Australia and the other floor in Queensland containing Spotted Gum. Both slabs have moisture barriers applied and in one instance the adhesive is peeling off the moisture barrier and in the other the adhesive is bonding to the vapour barrier but not the board.

Photo 15 – Adhesive peeling off the moisture barrier

Photo 16 – Adhesive adhering to the slab but not the prefinished board.

It is evident that the extensive use of adhesives with timber flooring is permitting flooring system installation methods and board profiles and sizes to be installed that were not considered possible in the past. However, it cannot said that such changes have not had their fair share of problems each of which damages the industry to some extent. Even though it must be recognised that wherever there is a failure there are also likely to be many similar floors that are performing well, some difference in one of the products, their application or fixing, the sub-floor or environmental effects or a combination of these, is different when a failure occurs. As such it is necessary to evaluate each installation method as a system as it is clear that the performance of one product affects the performance of another product that it is used with.

3.0 Adhesives and floor fixing

Not too long ago adhesive use with timber flooring was mainly associated with parquetry. Construction adhesives were introduced and builders laying timber floors began to use them when secret fixing strip floors to joists. Since that time polyurethane flooring adhesives have entered the market and their use is now extensive with floors laid directly to joists, to sub-floors of plywood and particleboard and direct stick to concrete slabs. As such adhesives play an important role in the fixing of timber floors and have provided timber floor options not previously available. However, the introduction of new products and new methods has not been without its problems and as outlined above, there have been a significant number of marketplace issues involving adhesive, even though they may not be the direct cause. More recently in the Australia market, there have been an increasing number of products available and the changes that are being made to products will continue. With new developments and the need to meet increasingly stringent environmental constraints, changes in formulations are occurring.

The timber flooring industry generally recommends the use of polyurethane flooring adhesives and provides general guidelines on combined mechanical and adhesive fixing of floors to joists and sheet flooring. Use of full bed adhesive and direct fix to slabs is not provided for in current public timber industry recommendations. The reason for this is the added complexity with some substrates and the fact that such systems are more specialized in nature, generally requiring much greater care, knowledge and experience.

Often when discussing adhesives it becomes apparent that adhesive manufacturers rely on experience from overseas where the timber species and internal building environment can differ markedly from Australia or the focus is on the adhesive bond and not the floor performance. However, not withstanding this generalisation, we do need to be careful and need to acknowledge that some adhesive manufacturers do put effort into understanding the whole picture. The point does however need to be acknowledged that just because an adhesive can create a strong bond between timber and a substrate, it does not ensure a floor's performance in terms of board peaking, shrinkage or cupping and those aspects outlined in Section 2 above.

The question is also asked, "are all polyurethane adhesives the same?" A statement in the FWPA installation guidelines that indicates 'use a polyurethane flooring adhesive' would suggest little difference but it must be recognised that these recommendations are for combined mechanical and adhesive fixing. It is clear that the adhesives are quite different in their properties, with some manufacturers marketing flexible adhesives while others have formulations that are less flexible or at times termed as semi-rigid. It is also becoming increasingly evident that there are many other properties of adhesives that also differ from one product to another.

Such aspects as their viscosity, that some take longer to cure under dry conditions than others and that some appear to adhere better to some sub-floors than others.

It is of interest that in the previous FWPA research project the expansion in Spotted Gum flooring panels was dependent on the quantity of adhesive but not whether it was ‘flexible’ or ‘semi rigid’(refer Figure 2 and 3).

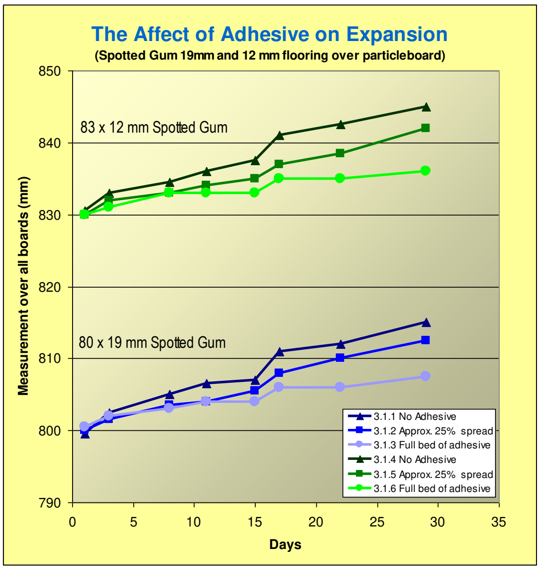


Figure 2 – Adhesive and floor expansion
FWPRDC PROJECT 03.2104 Milestone Report 5/6

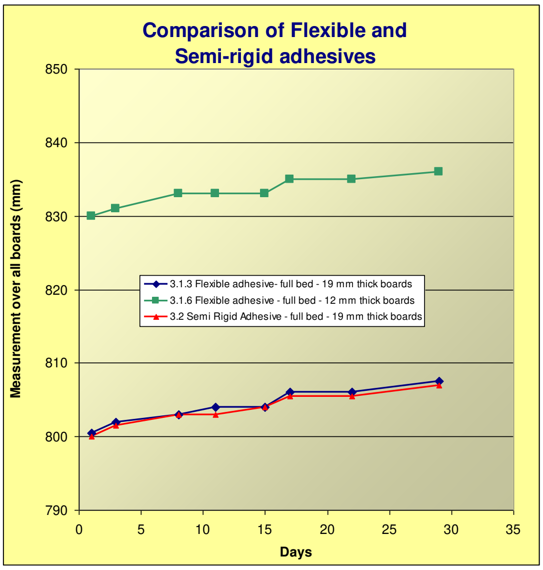


Figure 3 – Flexible & Semi rigid adhesives
FWPRDC PROJECT 03.2104 Milestone Report 5/6

Hence in this case it would appear that both types of adhesive provided similar restraint and neither was able to prevent board movement. The case may have been different with lower density and lower strength hardwood or with softwoods. Similarly, the swelling strength of the flooring is also related to board thickness, hence thinner boards may show increased constraint compared to thicker boards.

To provide some further insight into this interaction we may consider both the swelling stress of timber and the strength development of adhesives. The swelling stress developed by timber is largely proportional to its density and therefore species such as Spotted Gum will produce greater forces than say Tasmanian Oak, for a particular moisture uptake (not taking into consideration cutting pattern etc.). As such the indicative graph of Figure 4 illustrates this difference in swelling stress.

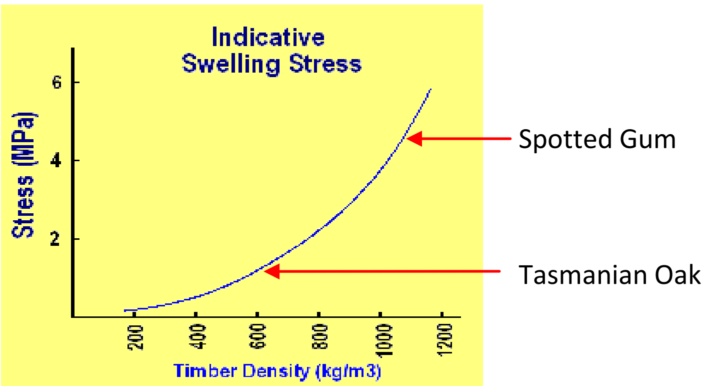


Figure 4 – Indicative timber swelling stress
Source: Adapted from information provided by Uroxsys Ltd

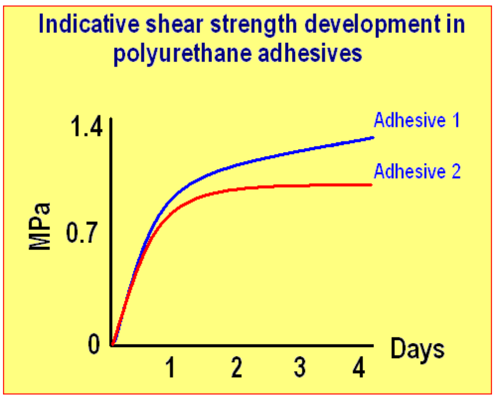


Figure 5 – Indicative adhesive shear strength
Source: Adapted from information provided by Uroxsys Ltd

The swelling stress will and associated swelling movement will transfer to adjacent flooring elements resulting in shear in the fixing. Similarly, when we consider adhesives they will develop strength with time and one adhesive may cure to a higher strength than another (refer Figure 5) and over a different time period. Adhesives can also be formulated to higher or lower shear strengths and tensile properties. It is evident from the indicative example in these graphs that the restraining force of the adhesive is more in line with the swelling stress of Tasmanian Oak and therefore greater restraint would be expected in lower density hardwoods.

These graphs highlight that with the range of adhesives that are available, they can be expected to have different final strengths and that their curing periods will also differ. The polyurethane flooring adhesives are moisture curing and therefore the curing rate is affected by the relative humidity of the air and the moisture available from the sub-floor and flooring. Such aspects can be expected to have a direct influence on board restraint after laying. If flooring is of low moisture content and installed in a moist environment some have suspected that initial movement of the timber flooring, particularly if pinned to a concrete slab, has been sufficient to compromise the bond during the curing period of the adhesive.

When considering the use of predominantly adhesive fix, and particularly over concrete slabs, there are many aspects that require consideration in terms of preparation and use. A number of these aspects are listed as questions below:-

- What condition does the slab surface need to be in?
- If a previous coating has been applied to a slab (e.g. concrete curing agent) how are these to be removed?
- What should the adhesive not be applied over?
- How flat does the slab need to be?
- If no vapour barrier is to be applied to the slab, what are the moisture related requirements?
- What are the moisture related requirements for other types of sub-floors?
- What do you use to measure these moisture related requirements and are such methods in common use?
- Do slab preparation requirements differ between ground floor slabs and elevated slabs?
- Should advice be provided concerning the suitability of the timber flooring for laying?
- What size trowel is to be used?
- When laying the floor how are the boards to be held in place?
- How long before the floor can be sanded?
- How long does it take for the adhesive to fully cure?
- What practical tests does the adhesive manufacturer suggest to determine if a sub-floor is acceptable?
- What conditions of temperature and relative humidity are appropriate for using the adhesive?

When floors are being laid with a full bed of adhesive, installers rely on the data sheets provided by the both flooring manufacturer (if available as the product may not be manufactured with the intention of direct fix) and the adhesive manufacturer. The answers to the questions outlined above should be available from such datasheets. However, it is apparent that in many of the datasheets the information can be either vague or no clear advice is given. Hence there are marked differences between one datasheet and another. Recommendations associated with one brand of adhesive often differ from another (e.g. slab flatness and sub-floor preparation). Due to this diversity, it is difficult to generate generic recommendations but the information currently available is considered to be incomplete and in need of better rationalization for the industry.

4.0 Profile design

The product lines to which solid flooring is being manufactured are the traditional 19 mm flooring generally ranging in cover width from 60 mm to 130 mm. Most manufacturers still indicate that the 130 mm wide profile is for top (face) nailing although one manufacturer has recommendations for secret fixing but under tighter humidity constraints. Most material appears to be center milled however a small proportion is off centre milled. The 19 mm hardwood flooring for fixing either direct to joists or over a sub-floor of plywood, particleboard or battens is generally closely aligned to AS 2796 profile dimensions. There is some thicker wide board material on the market such as 180 x 21 mm. This type of material is even more prevalent with those producing recycled timber flooring. Similarly, for some specific high load applications there is a limited amount of 60, 80 or 130 x 31 mm thick flooring being produced. However, even within the 19 mm thick wider board flooring there are many different profile designs on the market. The images in Figure 6 illustrate some of these differences for a 108 mm wide board and a number of 130 mm wide boards.

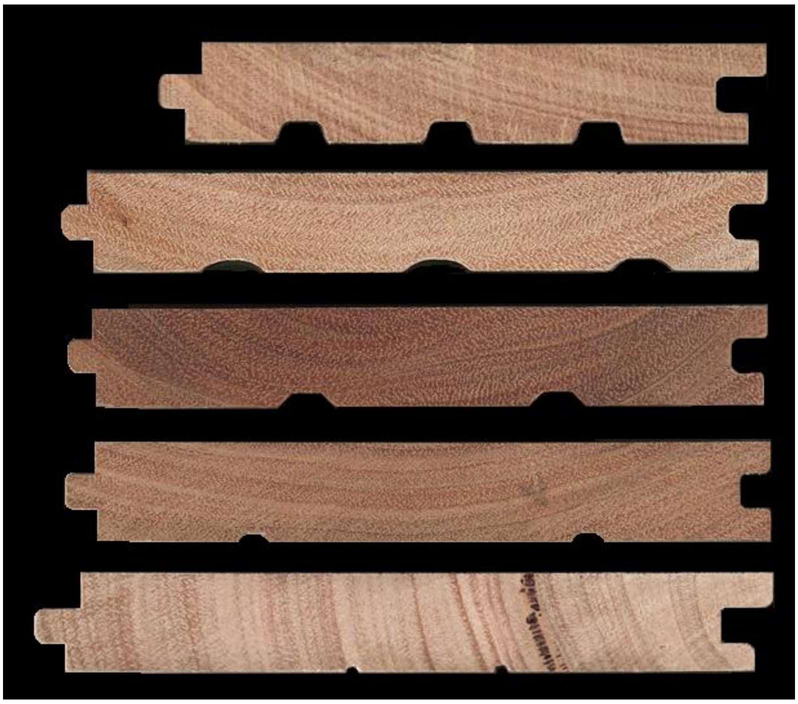


Figure 6 – Wide board flooring profiles

The profiles in Figure 6 include standard profile and secret nail profile with its wider shoulder above the groove, some have wide deep grooves in the lower surface of the boards while in others grooving is minimal. Not so apparent from the photograph is the amount of undercut (difference between top and bottom cover widths) which varies from about 0.4 mm to over 1mm. When considering these profile differences in-service performances must also be considered as differing.

When it comes to overlay and direct stick flooring, AS 2796 provides minimal guidance and due to this anything and everything is being produced. Thickness in millimeter increments from 8 mm to 14 mm is common. Tongue and groove dimensions and locations, as well as the degree of undercut vary greatly. Additionally some manufacturers are also deep splitting larger end-section material and producing flooring from it. However, drying stresses and moisture gradients can result in a product that is not stable after machining. To visualise some of the variability Figure 7 provides some scanned images of overlay flooring. It should however be noted that 180 x 21 mm flooring has also been used by some for secretly fixing as an overlay floor.

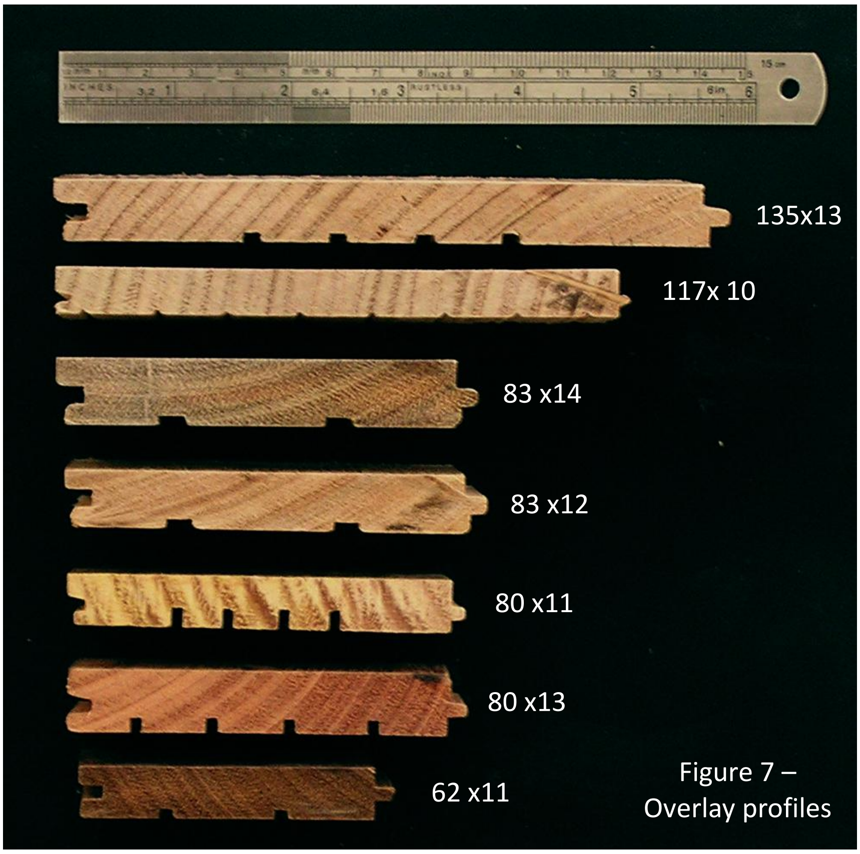


Figure 7 – Overlay profiles

When considering the optimum profile not only do pressure effects from floor expansion and movement characteristics need to be considered but also aspects associated with methods of fixing, whether it is mechanical or adhesive. This is particularly so with thinner overlay flooring. Board width to thickness ratio also affects stability and where boards are not held mechanically, board straightness and stability become of increasing importance. Some manufacturers are more in tune to this than others and straighten raw product during the machining process. It should also not be overlooked that manufacturing processes do vary vastly from one producer to another. This is not only in the machining of the boards but also with drying practices, in terms of average moisture content, moisture content range and moisture gradient within pieces. As such although two packs from different manufacturers may comply with the requirements of AS 2796 the performance of the products may differ markedly in the marketplace under the same environmental conditions. Therefore, when considering alternative fixing recommendations it must also be considered that product manufacturing differences will affect performance.

Grain deviation from tree to tree and between species will also differ markedly and influence the stability of the final product irrespective of the manufacturing process. Some manufactured product may be more suitable for installation over joists whereas other material with different dimensions is more suited to laying over particleboard or plywood. To facilitate the ease of laying with adhesive over a structural sub-floor the shoulders are often rounded however it appears that this can also be excessive. With reference to the scanned images in Figure 8, note the subtle differences in profile around the tongue and groove and also the relief grooves in the lower surface of the boards. While Figure 8 relates to 80 mm wide flooring it should be noted that thinner overlay flooring is just as, if not more, diverse.

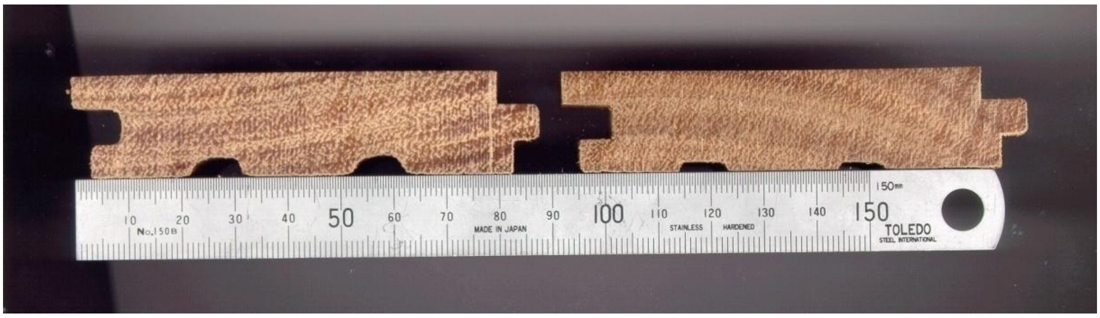


Figure 8 – Tongue and groove differences

If we were to consider Oak from the USA then the profile is that shown in the scanned image of Figure 9.

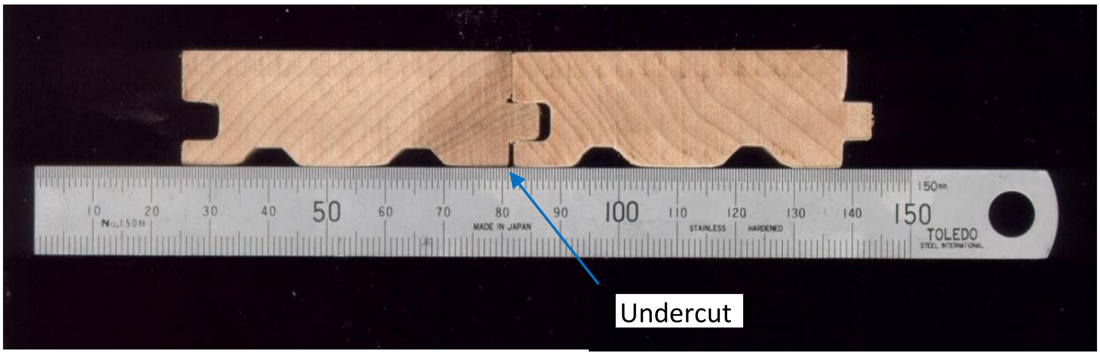


Figure 9 – North American Oak flooring profile

It is evident from the profile above that undercut is present in the USA profile as it is in the Australian profiles, although it must also be recognized that in the USA mechanical fixing predominates with this profile and the species is not as hard as many of our common hardwoods. With the marketplace issues associated with undercut, it may be questioned why it is included in the profile design at all. In previous years plain end flooring boards could often be flipped for 'best face up' and in such flooring the boards had no undercut. With the advent of secret nail profiles, grooves in the lower surface of the boards and undercut became prevalent. The undercut ensuring that the top face of adjacent boards would fit tightly together. Without undercut, if a board was to cup slightly, then the lower cover width would exceed the upper cover width and this would cause gapping at the board edges on the upper exposed surface at the time of laying. It is mainly for this reason that undercut is provided in floor profiles and this is particularly so with the introduction of wider thinner boards that often appear more prone to cupping and the extensive use of adhesive, which can make boards difficult to fit without undercut.

Currently the only fixing recommendations for boards wider than 85 mm is for top nailing and to meet fixing length requirements this necessitates a 35 mm depth of batten. In some states many are secret fixing wider boards to a plywood sub-floor with a full bed of adhesive however there are no generic written recommendations to support this practice. As indicated above one manufacturer does provide written recommendations for secret fixing with adhesive130 x19 mm boards over a subfloor, but has restrictions on the environmental conditions that this practice is suitable for. In Western Australia direct adhesive fix to concrete slabs is common, particularly with thin overlay material to 135 mm in width or wider. Such practices although not without their problems are working for flooring manufacturers, installers and consumers. As such it is these aspects with wider and thinner material, along with the design of the profile that are being focused on in this project through the use of chamber trials and finite element analysis.

In the work undertaken it was considered that a number of aspects needed to be evaluated to determine elements of profile design that enhance performance under various combinations of adhesive/mechanical fixing restraint. Where the standard 80 x 19 mm floor was well suited to mechanical fixing on joists and required this thickness to provide a structural floor, overlay flooring and wide board secret fixing necessitates the use of adhesive.

Following the chamber trials of the previous FWPA research, Mr Ransi Devendra from Uroxsys Ltd in New Zealand evaluated some of the trial outcomes by finite element analysis. This in effect creates a mathematical model of the floor board and it fixing, and evaluated the changes that occurred with the expansion and shrinkage from changing environmental conditions. In addition to this Timber Queensland Ltd met with Uroxsys Ltd and flooring manufacturers to propose a modified profile and it too was evaluated by finite element analysis.

From this work Mr Devendra found that:-

- When fixed using adhesive, the AS2796 profile with undercut gave greater peaking than the modified profile which had 'no' undercut and increased upper shoulder thickness (Figure 10 to 11). The modified profile was also an improvement over the AS 2796 profile with 'no' undercut (Figure 12).

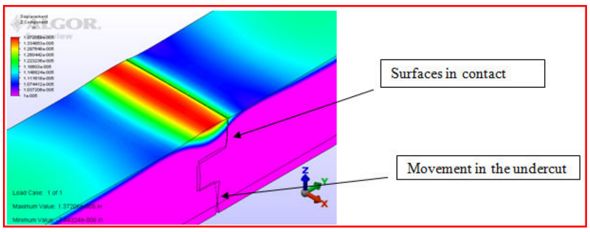


Figure 10 – AS 2796 Profile

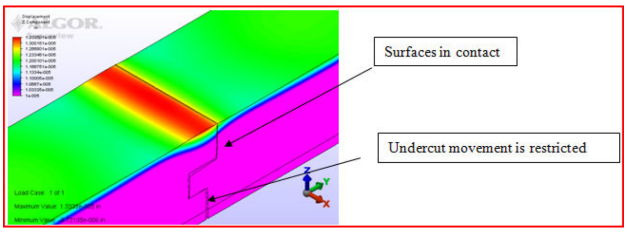


Figure 11 – Modified Profile – No undercut and thicker shoulder above the groove

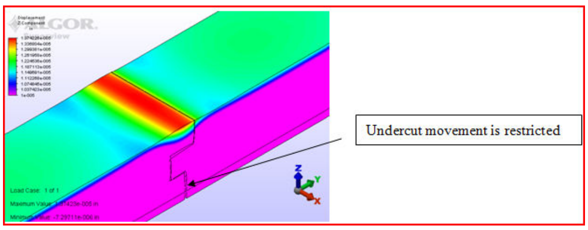
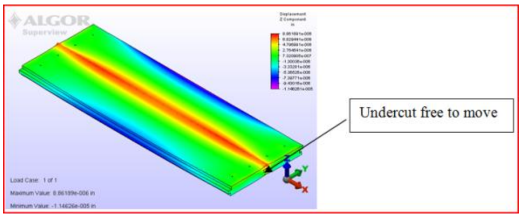


Figure 12 – AS 2796 profile with no undercut Source: Unpublished report by Ransi Devendra – Uroxsys

- That top nailing with 'no' undercut yielded reduced peaking than with undercut (Figures 13 & 14). This was consistent with the trials that were undertaken in the previous FWPA chamber trial research.



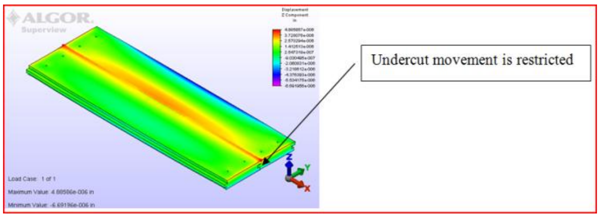


Figure 13 – Undercut profile, nail fixed to joists Figure 14 – No undercut, nail fixed to joists
Source: Unpublished report by Ransi Devendra – Uroxsys

For completeness photos from the previous research are provided in Photos 17 and 18. These illustrate the peaking that occurred and which has been modeled above. It should be noted that ten different boards were used and then the boards were matched for each panel. Peaking associated with the undercut is clearly evident.

Photo 17 – Two panels subjected to the same higher humidity environment

Photo 17 – Heavily undercut profile peaking under humid conditions.

With the wide variety of profiles being manufactured, the market is really doing as it pleases. What was considered to be more risky in the past is now more common and is also being supported by larger manufacturing companies in the products that they produce. For example, secret fixing of wide board flooring and the manufacture of 180 x 10 mm boards for direct stick to concrete. However, products and practices are very much 'state' related and flooring problems still abound throughout Australia and can often be attributed to product/fixing combinations that are risky, sub-floor conditions that are not correctly assessed and the influence of the in-service environment.

5.0 Research outline and methodology

The application of finite element analysis to timber flooring is a new concept however its potential has already been established. Through a combination of chamber trials and finite element analysis, it was considered that a model could be developed that estimated the performance of a profile with its corresponding fixing method, in differing environmental conditions. The chamber trials provide the interface between in-service floors and the model. That is, through chamber trials a number of profiles and fixing arrangements can be simultaneously assessed under controlled conditions. From this the model could be developed and verified and once achieved this could be used to predict performance without the need for testing an extensive range of options in chamber conditions.

The series of chamber trials included in this report focused on assessing the interactions of board movement with different adhesives in wider board flooring. In addition to this, insights into the effects of profile thickness and design, on performance were investigated. As such a better understanding of the secret fixing requirements of wide board flooring was being sought.

Four polyurethane flooring adhesives were used, two of which may be regarded as being flexible and two that were more rigid on curing although one of these probably sits about midway between very flexible and very rigid.

Each adhesive was tested with 130 mm x 19 mm wide material with secret stapling and boards with both large and small grooves on the underside were included. It was suggested by one adhesive manufacturer that the additional stretch permitted with flexible adhesives in deeper under board grooves would provide less restraint to cupping. We were also interested in the overall movement and the ability of adhesives to resist cupping in an environment that would induce it. In addition to this the overall performance of the two 130 mm wide profiles used was assessed.

Thinner and wider material (approx 80 to 140 mm wide) with a range of thicknesses (10 to 19 mm) was tested. This is typical of the material being directly fixed to slabs, particularly in Western Australia. One further trial covered the very wide 180 x 21 mm material also present in the market. It too was secretly fixed over a full bed of adhesive and its performance assessed against narrower and thinner profiles.

The test species used represent common products and their application in the market, and consist of:-

Spotted Gum – a high density, strong and slow responding species

Tasmanian Oak – medium density and faster responding species

The chamber trial initially created a dry environment to assess the performance under such conditions, followed by high humidity conditions where we expected any cupping to diminish and overall expansion of the flooring sections to occur.

Following this, dry conditions were again introduced which were expected to preferentially pull moisture from the upper exposed surface and induce conditions of severe cupping.

In total 16 panels were used in the trial.

Six panels of 130 mm wide flooring were tested with each panel containing both Spotted Gum and Tasmanian Oak. Adhesives differed between panels (refer Figure 15).

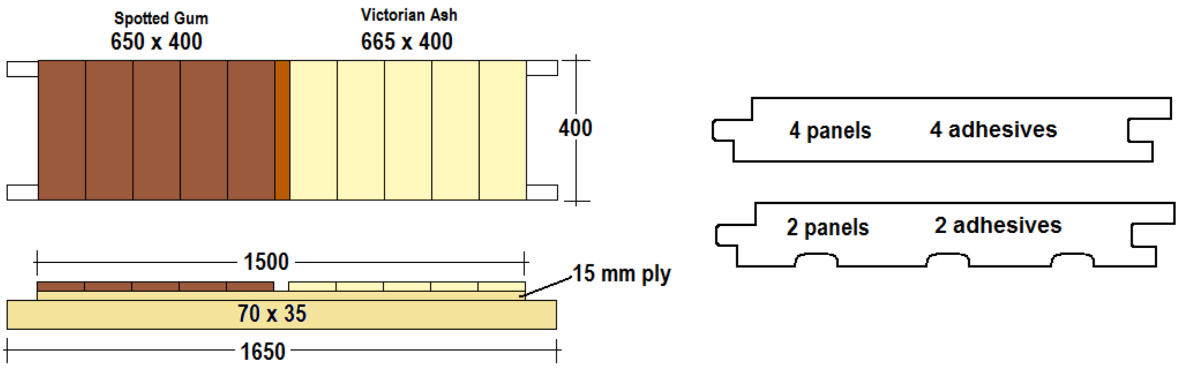


Figure 15 –panels with 130 mm wide boards

Ten panels with boards ranging in size and included 83 x 12, 117 x 10, 135 x 13, 80 x 19, 85 x 19 and 180 x 21. The 80 x 19 and 85 x 19 were included for comparative purposes to gage relative performance. Generally these panels were as shown in Figure 16.

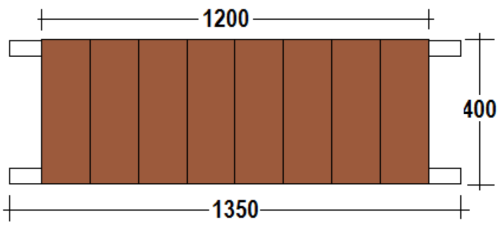


Figure 16 – Panels with a variety of board widths

Moisture content change of the flooring in the panels was estimated using sample boards and calculated from mass change.

The desired chamber test conditions were:-

- 30°C and 35% RH (6.7% EMC) for 14 days
- 30°C and 85% RH (17.5% EMC) for 18 days
- 30°C and 30% RH (6.0% EMC) for 10 days

At the start of the trial and when the chamber conditions were changed, the total width over the boards in each panel was measured noting the degree of cupping, gapping and splitting. Sample boards were also weighed to enable moisture contents to be estimated.

6.0 The flooring material and its properties

The flooring used in the trial panels were fabricated with both Tasmanian Oak flooring and Spotted Gum flooring. Table 3 for Tasmanian Oak outlines the specifics of cover widths, oven dry moisture contents, approximate unit movement, cupping and undercut (relief). Table 4 provides similar information for the Spotted Gum flooring.

Table 3

TASMANIAN OAK FLOORING PROPERTIES

Tas Oak		Initial Top Cover width	Bottom Cover width	Moisture Content	Movement per % MC change	Unit movement	Undercut	Cup	AV MC	AV U/cut
85x19		85.12	84.49	11.6%	0.24	0.29	0.63	0.00	11.6%	0.63
117x10	1	117.06	116.94	9.6%	0.24	0.21	0.12	0.25		
	2	117.02	116.86	9.4%	0.26	0.22	0.16	0.15		
	3	117.26	116.98	9.0%	0.20	0.17	0.28	0.00		
	4	117.06	116.89	9.2%	0.16	0.13	0.17	0.10		
	5	117.26	117.17	9.4%	0.26	0.22	0.09	0.10		
	6	117.08	116.88	10.0%	0.23	0.20	0.20	0.10		
	7	117.11	116.91	9.5%	0.27	0.23	0.20	0.35		
	8	117.09	116.87	9.1%	0.17	0.15	0.22	0.10		
	9	117.14	116.94	8.3%	0.29	0.25	0.20	0.15		
	10	117.02	116.84	9.6%	0.21	0.18	0.18	0.20	9.3%	0.182
133x19	1	133.29	132.99	10.7%	0.23	0.17	0.30	0.00		
	2	133.06	132.54	11.5%	0.24	0.18	0.52	0.00		
	3	133.02	132.51	11.3%	0.35	0.26	0.51	0.00		
	4	133.14	132.58	11.0%	0.24	0.18	0.56	0.00		
	5	132.87	132.30	10.8%	0.29	0.22	0.57	0.00	11.1%	0.49
135x13	1	134.79	134.20	9.5%	0.32	0.24	0.59	0.00		
	2	134.86	134.58	9.6%	0.25	0.18	0.28	0.40		
	3	135.08	134.45	10.6%	0.38	0.28	0.63	0.00		
	4	134.34	134.04	10.3%	0.39	0.29	0.30	0.10		
	5	134.85	134.40	9.8%	0.29	0.21	0.45	0.00		
	6	135.26	134.69	9.1%	0.30	0.22	0.57	0.00		
	7	134.98	134.21	10.3%	0.41	0.30	0.77	0.25		
	8	134.76	134.41	9.0%	0.41	0.31	0.35	0.35	9.8%	0.49

There are a number of aspects to be noted from Table 3 as follows:-

- The 117 x 10 mm off-centre milled profile with a micro tongue was fairly consistent in moisture content with an average of 9.3%, had a small amount of undercut (difference between top and bottom cover widths) of 0.2 mm and a number of pieces contained minor cupping.
- The 133 x 19 mm centre milled standard profile was consistent in moisture content with an average of 11.1%, had an undercut of 0.5 mm and was free from cupping.

- The 135 x 13 mm centre milled secret nail profile was also consistent in moisture content with an average of 9.8%, had an undercut of 0.5 mm and a number of the pieces contained minor cupping.
- The panel of 85 x 19 was added to the trial for comparative purposes and consisted of sections off two boards, the details of one being provided here. The moisture content was 11.6%, the undercut was 0.6 mm and no cupping was present.
- Sections of the boards in the samples that are highlighted in bright yellow were used to estimate the chamber moisture content.

Table 4

SPOTTED GUM FLOORING PROPERTIES

Spotted Gum		Initial Top Cover width	Bottom Cover width	Moisture Content	Movement per % MC change	Unit movement	Undercut	Cupping	AV MC	AV U/cut
80x19		79.82	79.28	11.6%	0.29	0.36	0.54	0.00	11.6%	0.54
83x12	1	83.12	82.57	9.7%	0.28	0.33	0.55	0.00		
	2	82.82	82.80	10.5%	0.31	0.37	0.02	0.60		
	3	83.11	82.56	9.8%	0.28	0.34	0.55	0.00		
	4	83.18	82.48	9.7%	0.28	0.33	0.70	0.00		
	5	82.98	82.62	9.8%	0.28	0.34	0.36	0.10		
	6	83.08	82.62	9.2%	0.31	0.37	0.46	0.10		
	7	83.15	82.72	8.8%	0.23	0.28	0.43	0.10		
	8	83.14	82.73	9.6%	0.27	0.33	0.41	0.00		
	9	83.21	82.77	10.3%	0.25	0.30	0.44	0.00		
	10	83.05	82.56	9.1%	0.26	0.32	0.49	0.00	9.7%	0.44
130x19	1	130.34	130.45	9.7%	0.47	0.36	-0.11	0.65		
	2	130.16	130.02	10.7%	0.44	0.34	0.14	0.25		
	3	130.16	130.10	10.1%	0.45	0.35	0.06	0.25		
	4	130.00	129.88	10.9%	0.44	0.34	0.12	0.55		
	5	129.72	129.60	11.0%	0.41	0.31	0.12	0.30	10.5%	0.07
180 x 21	1	180.27	178.84	11.2%	0.55	0.30	1.43	-0.10		
	2	180.23	178.70	11.3%	0.63	0.35	1.53	0.10		
	3	179.89	178.55	11.2%	0.54	0.30	1.34	0.10		
	4	179.85	178.35	11.3%	0.54	0.30	1.50	0.00		
	5	180.14	178.54	12.0%	0.60	0.33	1.60	0.00		
	6	179.94	178.46	10.9%	0.53	0.30	1.48	0.00	11.3%	1.48

From Table 4 the following needs to be noted:-

- The 83 x 12 mm centre milled profile was consistent in moisture content with an average of 9.7%, had an undercut of 0.4 mm and minimal cupping.
- The 130 x 19 mm centre milled standard profile was consistent in moisture content with an average of 10.5%, had a minimal undercut of 0.1 mm and moderate cupping. It should be noted that cupping in a board reduces the amount of undercut. As some cupping can occur due to drying stress and moisture redistribution after machining, this highlights the need to provide some undercut. Wider and thicker boards are often more prone to cupping from drying stress effects. In the board with the most cupping the bottom

cover width was slightly wider than the top cover width. The material was however probably machined with about 0.4 mm of undercut.

- The 180 x 21 mm centre milled standard profile was consistent in moisture content with an average of 11.3%, had an average undercut of 1.5 mm and there was minimal cupping.
- The panel of 80 x 19 was added to the trial for comparative purposes and consisted of sections off three boards, the details of one being provided here. The moisture content was 11.6%, the undercut was 0.5 mm and no cupping was present.
- Sections of the boards in the samples that are highlighted in bright yellow were used to estimate the chamber moisture content.

In terms of moisture content and machining all boards supplied for the trial were considered to meet the requirements of AS 2796 – Timber – Hardwood – Sawn and milled products. Average moisture contents ranged from 9.3% to 11.6% and this could be expected to result in some in-service performance differences. Similarly it should be noted that the majority of the Tasmanian Oak was quartersawn while the majority of the Spotted Gum was backsawn.

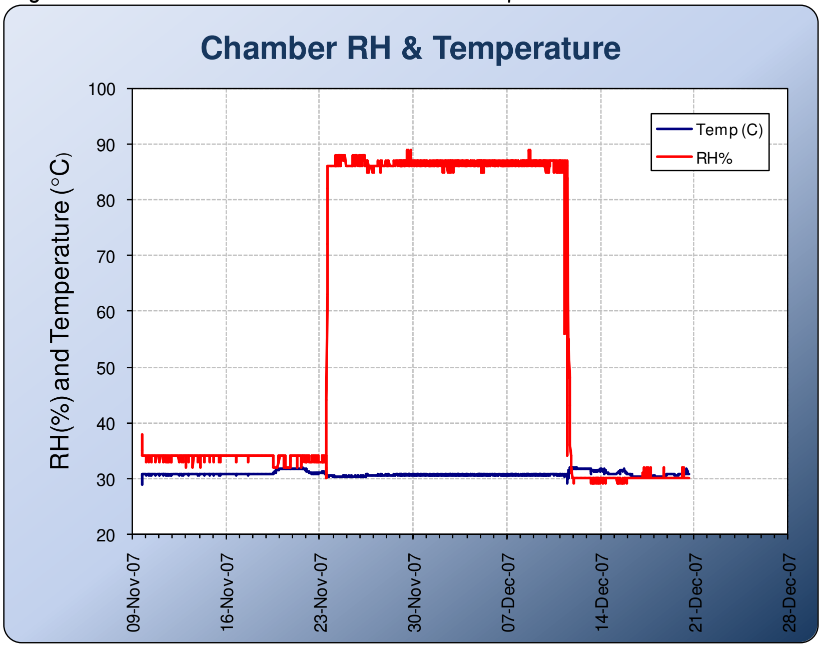
7.0 Chamber Conditions

A controllable environment chamber at ENSIS (CSIRO) in Melbourne was used for the trial and it is shown in Photo 18. Data loggers were placed in the chamber to check on the conditions inside the chamber during the trial. A printout of temperature and humidity is shown in Figure 17 and it indicates the following conditions:-

- Stage 1 30°C and 34% RH giving and EMC of 6.6% for 14 days
- Stage 2 30°C and 86% RH giving and EMC of 17.9% for 18 days
- Stage 3 30°C and 30% RH giving and EMC of 6% for 9 days

Photo 18 – Environment chamber

Figure 17 – Environment chamber RH and temperature



8.0 Results and discussion

Prior to discussing the results it should be recognised that the flooring and panels were chosen to evaluate a number of different aspects. That is there were a number of panels with 130 mm wide flooring as well as boards of various cover widths and thickness that the 130 mm wide boards were part of. Hence the results have been broken up into a number sections covering the respective areas.

8.1 Overall movement of boards in the panels

The overall movement in the panels is initially reported on as this provides a more global view of trial. Each panel experienced dry conditions followed by moist conditions and then dry conditions again. In stage 1, initial shrinkage was basically within board but during the high humidity stage all panels experienced expansion. Regarding the adhesives two flexible and two semi-rigid polyurethane adhesives were used. These are referred to in the report as FL-1 and FL-2 for the flexible and SR-1 and SR-2 for the semi-rigid adhesives. Two panels are denoted 130 x19 – G. These two panels had larger grooves machined into the lower surface of the boards. Note that the moisture contents have been estimated from the change in mass of sample boards within the chamber. In reality these are indicative of the maximum that the flooring would achieve but does not account for the induced moisture gradients that would occur with the adhesive fixing.

Table 5 provides the measurements for the Tasmanian Oak panels

Table 5

TAS OAK panel movement and estimated moisture contents

			Initial conditions		Stage 1: Dry cond.		Stage 2: Moist cond.		Stage 3: Dry cond.	
No.	Panel		Estimated MC	Panel widths 7/11/07	Estimated MC 23/11/07	Panel widths 23/11/07	Estimated MC 11/12/07	Panel widths 11/12/07	Estimated MC 20/12/07	Panel widths 20/12/07
1	85x19	FL-1	11.6%	1110.0	8.5%	1108.0	13.1%	1113.5	9.5%	1109.0
2	117x10	FL-1	9.3%	1174.0	6.6%	1171.4	13.6%	1176.5	6.3%	1172.0
3	117x10	SR-1	9.3%	1175.0	6.6%	1172.5	13.6%	1177.5	6.3%	1172.5
4	133x19	SR-1	11.1%	663.0	7.6%	662.0	13.6%	664.5	8.1%	662.5
5	133x19	SR-2	11.1%	664.0	7.6%	661.5	13.6%	664.5	8.1%	662.5
6	133x19	FL-1	11.1%	664.0	7.6%	662.5	13.6%	665.5	8.1%	663.0
7	133x19	FL-2	11.1%	663.0	7.6%	662.0	13.6%	664.0	8.1%	662.0
8	133x19 - G	SR-2	11.1%	663.0	7.6%	661.5	13.6%	664.5	8.1%	662.0
9	133x19 - G	FL-2	11.1%	663.0	7.6%	661.5	13.6%	664.0	8.1%	661.5
10	135x13	FL-1	9.8%	1078.0	6.8%	1076.5	13.2%	1082.5	6.8%	1078.0
11	135x13	SR-1	9.8%	1080.0	6.8%	1077.5	13.2%	1083.0	6.8%	1078.0

Aspects to note from these results are as follows:-

- The flooring in the panels experienced moisture content reductions of approximately 3% with the dry conditions of Stage 1, a moisture content increase of approximately 6% to 7% during Stage 2 and the final reduction of moisture content of approximately 6% to 7% in Stage 3. Hence the moisture contents at the end of dry conditions in Stages 1 and 3 were similar (within about 1%).
- At the end of the dry conditions of Stage 1 all panels experienced some reduction in width from shrinkage of individual boards. As such gapping between all boards was evident.

- At the end of Stage 2 all panels showed some overall expansion. In all instances this was quite small and indicates the restraint provided by adhesives. It is however important to note that even with the thin 117 x 10 mm flooring (Panels 2 & 3) the adhesives were not able to restrain expansion.
- It was evident that there was nothing conclusive to indicate that one adhesive was dominant in providing more restraint to movement than another. With reference to the 117 x 10 mm flooring (Panels 2 & 3) and the 133 x 19 mm flooring (Panels 6 & 4) similar movement between the flexible and semi-rigid adhesives was experienced. Movement in the 135 x 13 mm flooring (Panels 10 & 11) with the same adhesives was greater than the 117 x 10 mm flooring and movement variation between the two was also greater.
- Concerning the flooring with larger grooves machined into the lower surface (Panels 8 & 9) the movement was within the same bounds as the other 133 mm wide flooring panels.
- At the end of Stage 3 panel widths were generally less than initial panel widths. This is indicative of the Tasmanian Oak being of moderate strength and experiencing some crushing at board edges during expansion.

To summarize the important aspects from the points above it is considered that:-

1. Adhesives irrespective of the type will restrain expansion but will not prevent expansion, irrespective of the thickness of the flooring.
2. The movement characteristics were similar irrespective of the type of adhesive. This would suggest that aspects relating to timber properties and installation are equally or more significant.
3. Larger grooves machined into the lower surface of the boards did not influence the movement experienced.

Table 6 provides the measurements for the Spotted Gum panels

Table 6

SPOTTED GUM panel movement and estimated moisture contents

			Initial conditions		Stage 1: Dry cond.		Stage 2: Moist cond.		Stage 3: Dry cond.	
No.	Panel		Estimated MC 7/11/07	Panel widths 7/11/07	Estimated MC 23/11/07	Panel widths 23/11/07	Estimated MC 11/12/07	Panel widths 11/12/07	Estimated MC 20/12/07	Panel widths 20/12/07
12	80x19	FL-1	11.6%	1123.0	8.9%	1122.0	13.6%	1125.5	9.8%	1122.5
13	83x12	FL-1	9.7%	1165.0	7.4%	1164.0	14.9%	1173.0	8.2%	1167.0
14	83x12	SR-1	9,7%	1165.5	7.4%	1164.0	14.9%	1168.5	8.2%	1164.5
15	130x19	SR-1	10.5%	650.5	7.7%	648.5	13.5%	653.0	8.6%	650.0
16	130x19	SR-2	10.5%	650.5	7.7%	649.0	13.5%	653.5	8.6%	650.5
17	130x19	FL-1	10.5%	650.0	7.7%	648.0	13.5%	654.5	8.6%	650.5
18	130x19	FL-2	10.5%	650.5	7.7%	648.0	13.5%	654.0	8.6%	650.0
19	130x19 - G	SR-2	10.5%	650.0	7.7%	648.5	13.5%	653.5	8.6%	650.0
20	130x19 - G	FL-2	10.5%	650.0	7.7%	648.5	13.5%	654.5	8.6%	650.0
21	180x21	FL-1	11.3%	1081.5	8.7%	1078.5	14.4%	1089.0	9.5%	1081.5
22	180x21	SR-1	11.3%	1081.5	8.7%	1078.5	14.4%	1086.0	9.5%	1080.0

Aspects to note from these results are as follows:-

- The flooring in the panels generally experienced moisture content reductions of approximately 2% to 3% with the dry conditions of Stage 1, a moisture content increase of approximately 5% to 6% during Stage 2 and a final reduction of moisture content of approximately 5% in Stage 3. Hence the moisture contents at the end of dry conditions in Stage 3 were up to 2% lower than initial conditions. The exception to this was the thinner 12 mm material which was more reactive both in taking up and loosing moisture. This is to be expected, is consistent with other literature and is important when considering floor thickness with backsawn high density species.

- At the end of dry conditions of Stage 1 all panels experienced some reduction in width from shrinkage of individual boards. As such gapping between all boards was experienced.
- At the end of Stage 2 all panels showed greater overall expansion when compared to the Tasmanian Oak. This could be expected due to Spotted Gum being of greater strength and predominantly backsawn. Hence it could be expected that the adhesives would provide less restraint. It is important to note that again the adhesives were not able to provide restraint that would prevent floor expansion.
- It was evident that the semi-rigid adhesives provided greater restraint to movement that the flexible adhesives. Based on the percentage average movement of the six panels with flexible adhesive compared to the five panels with semi-rigid adhesive, the flexible adhesives permitted about a third greater expansion. Regarding the flooring with larger grooves machined into the lower surface (Panels 19 & 20) the movement was within the same bounds as the other 130 mm wide flooring panels.
- At the end of Stage 3 panel widths were more in line with initial panel widths. This is indicative of the Spotted Gum being a stronger timber and not experiencing crushing at board edges.

To summarize the important aspects from the points above it is considered that:-

1. Adhesives irrespective of the type will restrain expansion and will be less effective in provided restraint with stronger timbers.
2. The movement characteristics with the semi-rigid adhesives indicated about one third less expansion. The strength of the Spotted Gum was however quite dominant and the expansion even with semi-rigid adhesives far exceeded that of Tasmanian Oak.
3. Larger grooves machined into the lower surface of the boards did not influence the movement experienced.

Provided below are four photos which illustrate two wide board flooring panels at the end of drying in Stage 1 and swelling in Stage 2. In each photo two panels are shown, one with a semi-rigid adhesive and the other with a flexible adhesive. These photos enable the visual appearance particularly with respect to gapping at board edges to be assessed with the two adhesive types.

Photo 19 – Shrinkage at the conclusion of Stage 1 in Tasmanian Oak 135 x 13 mm panels

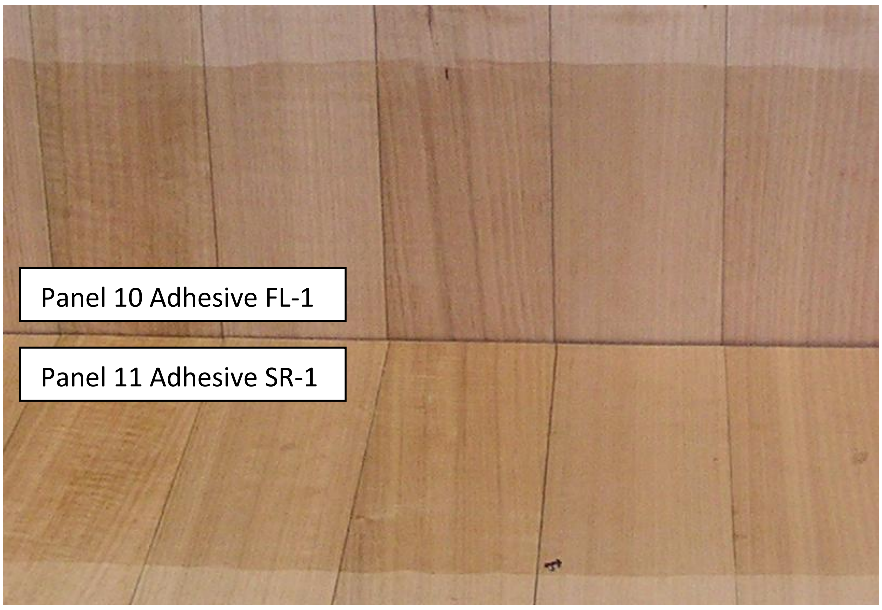


Photo 20 – Expansion at the conclusion of Stage 3 in Tasmanian Oak 135 x 13 mm panels

Photo 21 – Shrinkage at the conclusion of Stage 1 in Spotted Gum 180 x 21 mm panels

Photo 22 – Expansion at the conclusion of Stage 3 in Spotted Gum 180 x 21 mm panels

8.2 Cupping and shape changes

In addition to overall movement another equally important aspect that affects the appearance of a timber floor is the shape changes that can occur in the boards. It has been indicated above that conditions inside the chamber were designed to simulate floors that would experience very dry conditions within a dwelling followed by conditions associated with a moist environment and finally conditions that would induce cupping in the boards. Under such conditions the interaction of the adhesives to prevent or reduce cupping and other changes has been investigated.

Under initial dry conditions there would be a propensity for boards to both cup and possibly split, particularly with the possible extra restraining force of the adhesive on the lower surface. Under moist conditions boards would swell with gaps closing and the flooring would be under pressure, and as such subject to pressure effects that may be greater due to the adhesive's effect of reducing the overall expansion in the floor. When dry conditions are re-introduced preferential moisture loss from the upper exposed surface will create greater moisture gradients and hence conditions to induce cupping.

During the trial aspects relating to cupping, gapping and the appearance of each panel was recorded. All panels were sanded on the face down one side. This provided a smooth surface removing any initial cupping that may have been present in the supplied boards and any mismatch at board joints associated with machining or installation. Therefore there was a section of each panel that began the trial as a smooth surface free of undulations.

8.2.1 Cupping in the 130 mm and 133 mm wide flooring

A cupped appearance in a floor can occur for a number of reasons. That is moisture gradients induced from either dry conditions above the floor or moist conditions beneath a floor and also from pressure effects in a floor that causes boards to peak at their edges. In the trial, Stage 1 induced dry conditions above the flooring panels, in Stage 2 the cupped appearance is likely to be more associated with peaking and in Stage 3 the conditions are similar to Stage 1 however greater gradients can be expected due to the moisture uptake from Stage 2.

Cupping was measured at the end of each stage by placing a steel ruler across the boards and using feeler gauges to measure the cupping. The results for each board were recorded and the average of these results is reported.

The results initially cover the panels with the 130 mm and 133 mm nominal width flooring. In these panels all four adhesives were used. In addition to determining any difference between adhesive type, the effect of large grooves in the lower surface of the board to moderate cupping was also being investigated. With regard to this there were two schools of thought. Firstly that these grooves, at times referred to as anti-warping grooves, would be less prone to cupping and secondly that such grooves would result in less restraint from greater thickness of the adhesive and therefore provide less restraint to cupping, particularly with the more flexible adhesives.

Provided in Figures 19 & 20 are the results for the Tasmanian Oak panels and the Spotted Gum panels. As with graphs in the previous sections FL-1 and FL-2 refer to the flexible adhesives and SR-1 and SR-2 for the semi-rigid adhesives. The panels with the grooves are denoted FL-2-G and SR-2-G

Figure 19 – Tasmanian Oak – Average Cupping

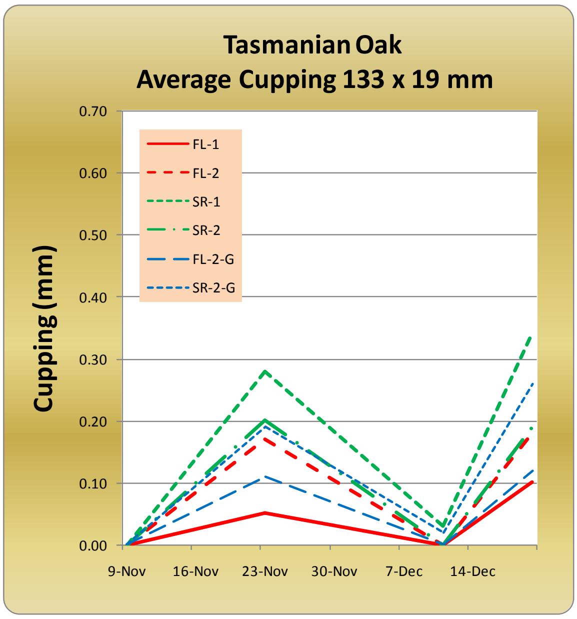
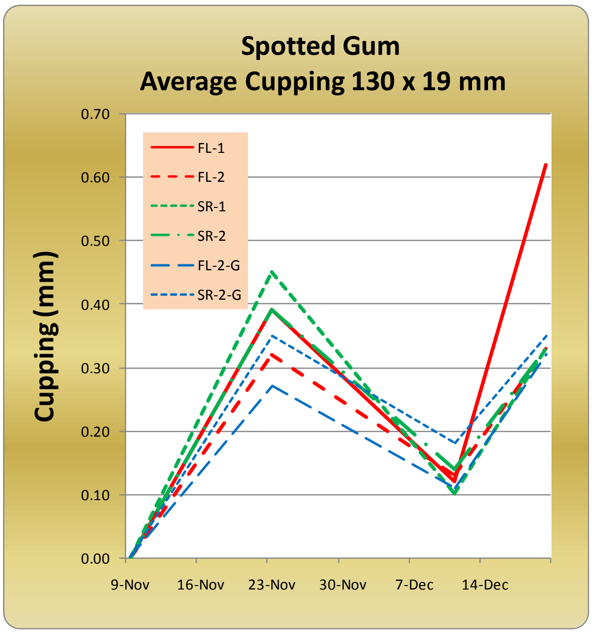


Figure 20 – Spotted Gum – Average Cupping



It is evident from these graphs that the cupping in the predominantly quarter sawn Tasmanian Oak was significantly less that the predominantly backsawn Spotted Gum. This is to be expected. However from the results there is nothing to suggest as a generality that semi rigid adhesives perform any differently than the more flexible adhesives. Similarly it would be differcult to conclude from the trial that the grooves in the bottom of the boards make a significant difference in affecting the degee of cupping that occurs.

It has to be emphasised that the characteristics of the timber itself has a predominant effect on the cupping present and this was highlighted by the variability in the cupping between sections of individual boards and the reason for the high degree of average cupping at the end of the trial in Spotted Gum with the FL1 adhesive.

To further clarify this it was apparent that some boards or sections of boards were naturally more prone to cupping than others. In the case of Spotted Gum it was considered that the strength of the timber, cutting pattern and characteristics of the individual board section controlled the degree of cupping and that it was largely moisture content dependent. To illustrate this Tables 5 shows two boards, one that had a high degree of cupping movement and one with much less cupping movement. It is evident from this that no movment pattern could be attibuted to the adhesive present but there does appear to be a relationship going from the lower humidty conditions of 23 November to the high humdity conditions of 11 December and back to low humdity conditions again at 20 December. If we look at the baord statistics at the beginning of the trial there was little that separated them. Both boards had some some initial cupping *(Board 1 - 0.65mm, Board 4 - 4 0.55 mm)*, both had moisture contents that were as expected *(Board 1 – 9.7%, Board 4 - 4 10.9%)*and the estimated unit movement of each board was similar*(Board 1 – 0.36, Board - 4*

0.34 mm). The point that needs to be considered it that this material does exist and at the time of manufacture there is nothing obvious to differentiate one from the other. The cupping although moisture related does not appear to be from high moisture content at the time of manufacture and this is probably what would be assumed if a number of such boards appeared in the one floor. Drying stresses may however be influential.

Table 7 – Cupping of sample boards at each stage

Spotted Gum Board 1

	23-Nov	11-Dec	20-Dec	*Ave*
FL-1	1.00	0.45	1.60	*1.02*
FL-2	0.40	0.15	0.40	*0.32*
SR-1	0.50	0.00	0.15	*0.22*
SR-2	0.50	0.35	0.30	*0.38*
FL-2-G	0.65	0.40	0.60	*0.55*
SR-2-G	1.10	0.80	1.00	*0.97*

Spotted Gum Board 4

	23-Nov	11-Dec	20-Dec	*Ave*
FL-1	0.10	0.00	0.20	*0.10*
FL-2	0.10	0.10	0.30	*0.17*
SR-1	0.40	0.10	0.35	*0.28*
SR-2	0.45	0.10	0.50	*0.35*
FL-2-G	0.30	0.00	0.40	*0.23*
SR-2-G	0.15	0.00	0.20	*0.12*

8.2.2 Cupping and appearance in the Tasmanian Oak panels

The Tasmanian Oak panels consisted of the following flooring sizes:-

- 117 x 10 mm
- 135 x 13 mm
- 133 x 19 mm

In each of these panels the cupping of two boards was measured which corresponded to the sample boards used to estimate the moisture content. In addition to this the cupping was recorded for the board where cupping was greatest. For each board type a flexible adhesive (FL-1) and semi rigid adhesive (SR-1) was used. The results are provided in Table 8 and comments corresponding to each board size are provided below including comments regarding the 85 x 19 mm panel.

Table 8 Cupping and Gapping present at each stage

Tas. Oak 117 x 10 Adhesive SR-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
4	0.25	0.00	0.25
6	0.25	0.00	0.25
max	0.55	0.1	0.55

Tas. Oak 133 x 19 Adhesive SR-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
3	0.10	0.00	0.20
4	0.00	0.00	0.10
max	0.10	0.00	0.20

Tas. Oak 135 x 13 Adhesive SR-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
4	0.35	0.00	0.30
6	0.00	0.00	0.10
max	0.7	0.15	0.85

Tas. Oak 117 x 10 Adhesive FL-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
4	0.25	0.25	0.25
6	0.15	0.10	0.15
max	0.3	0.2	0.3
Gapping	0.5-1.4	no gaps	0.5-1.2

Tas. Oak 133 x 19 Adhesive FL-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
3	0.8	0.15	0.80
4	0.3	0.00	0.15
max	0.8	0.15	0.80
Gapping	0.7-0.9	no gaps	0.8-1.1

Tas. Oak 135 x 13 Adhesive FL-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
4	0.50	0.45	0.75
6	0.00	0.00	0.08
max	0.8	0.5	0.9
Gapping	0.5-1.4	no gaps	0.8 -1.5

From Table 8 it is apparent that a cupped appearance was present in all panels and overall when considering all boards within the panels, the cupping appeared to be a little less with the semi rigid adhesive. However, this is not to say that some individual boards in panels with the semi rigid adhesive did not exceed those of panels with the flexible adhesive.

Gapping at board edges related to board width and this was to be expected. The panel of 85 x 19 mm flooring with flexible adhesive FL-1 was observed to perform similar to the above panels with minimal of cupping (0.1 mm max) and gapping up to 1.0 mm again reflecting the narrower cover width. In essence, the wider the board, the wider the gaps at board edges and the greater the cupping that can be expected.

Photo 6 shows a 117 x 10 mm board at the end of stage 3. This material performed well and the tongue and groove size and location was considered to have assisted. It should be noted however that such material cannot be mechanically fixed and relies solely on adhesive.

Photo 6 – 117 x 10 mm Tasmanian Oak

Photo 7 shows a 135 x 13 mm board also at the conclusion of the trial. Greater gapping and movement at board joints was experienced with this profile.

Photo 7 – 135 x 13 mm Tasmanian Oak

8.2.3 Cupping in the Spotted Gum panels

The Spotted Gum panels consisted of the following flooring sizes:-

- 83 x 12 mm
- 130 x 19 mm
- 180 x 21 mm

In each of these panels the cupping of two boards was measured which corresponded to the sample boards used to estimate the moisture content. In addition to this the cupping was recorded for the board where cupping was greatest. For each board type a flexible adhesive (FL-1) and semi rigid adhesive (SR-1) was used. The results are provided in Table 9 and comments corresponding to each board size are provided below including comments regarding the 85 x 19 mm panel.

Table 9

Spotted Gum 83 x 12 Adhesive SR-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
4	0.30	0.15	0.45
5	0.25	0.00	0.15
max	0.95	0.15	1.15

Spotted Gum 130 x19 Adhesive SR-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
1	0.50	0.00	0.15
3	0.55	0.10	0.55
max	0.55	0.3	0.55

Spotted Gum 180 x 21 Adhesive SR-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
3	0.70	0.00	0.40
5	1.10	0.10	0.85
max	1.10	0.30	1.20

Spotted Gum 83 x 12 Adhesive FL-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
4	0.15	0.40	0.70
5	0.2	0.30	0.50
max	0.85	?	0.85
Gapping	0.5-1.4	no gaps	0.6-1.4

Spotted Gum 130 x19 Adhesive FL-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
1	1.00	0.45	1.60
3	0.40	0.15	0.55
max	0.4	0.45	1.6
Gapping	0.5-1.5	no gaps	0.6-1.1

Spotted Gum 180 x 21 Adhesive FL-1

Board	Stage 1	Stage 2	Stage 3
	23-Nov	11-Dec	20-Dec
3	0.65	0.30	1.10
5	0.65	0.15	0.85
max	0.65	1.00	3.26
Gapping	1.6-2.4	no gaps	1.3 - 5.8

From Table 9 it is again apparent that a cupped appearance was present in all panels and more pronounced than the Tasmanian Oak. The cupping was also quite variable with one of two boards in a panel having considerably greater cupping than the others. The variability in the results was greater than with the Tasmanian Oak and any possible influence by the adhesive even less distinct.

Gapping at board edges was again generally consistent with board width. The panel of 80 x 19 mm flooring with flexible adhesive FL-1 was observed to perform in a similar manner to the panels above but with minimal of cupping (0.15 mm max) and gapping up to 1.0 mm. Under the more extreme conditions of the trial, movement of some boards was quite pronounced indicating that the strength on the timber far exceeded the ability of the adhesive to hold the board from moving.

Provided below are some photos showing the movement that occurred in the different board widths at the conclusion of stage 3.

Photo 8 – 83 x 12 mm Spotted Gum

Photo 9 – 130 x 19 mm Spotted Gum

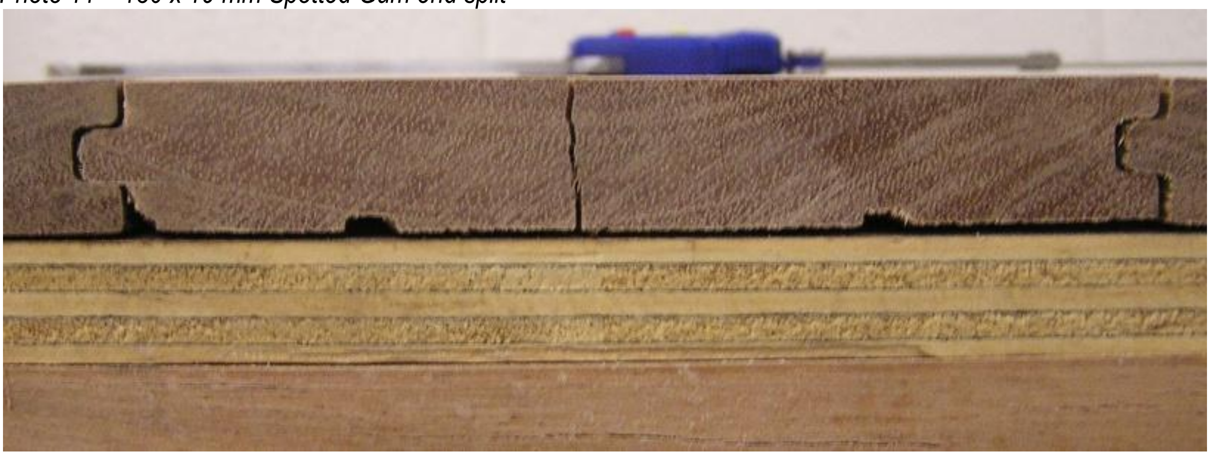
Photo 10 – 180 x 21 mm Spotted Gum

8.2.4 Splitting

It was outlined above that with restraint provided by the adhesive and under the conditions present in the chamber that it was possible for boards to split. During the trial there were a number of boards that had split from their ends and this ranged from small hairline splits to wider ones. Splits occurred in both Tasmanian Oak and Spotted Gum and with both flexible and semi rigid adhesives. The splits were present in the 130 mm & 133 mm wide material and the 180 x 21mm. As such the stress induced by greater moisture gradients may have contributed along with greater moisture loss from board ends.

Photo 11shows one of the more severe splits in a 130 mm Spotted Gum board.

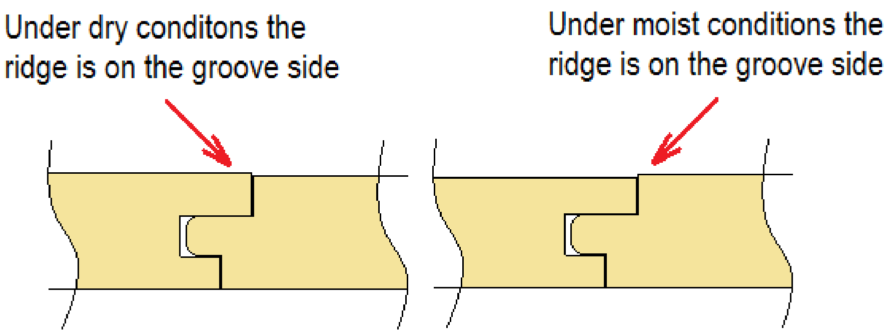
Photo 11 – 130 x 19 mm Spotted Gum end split



8.2.5 Ridges at board joints

One further observation from the trial was that all profiles, except the 117 x 10 mm Tasmanian Oak flooring with an off-centre milled micro tongue and groove, experienced ridges at board joints with moisture uptake and loss. This occurred with both secret nail and standard profile boards. When under dry conditions preferential shrinkage of the top of the boards caused the shoulder above the groove to rise and under moist conditions expansion caused the shoulder above the groove to fall. Due to this the ridges alternated from being on the tongue side of the boards to the groove side. This is shown in Figures 21.

Figure 21 – Ridging at board edges



8.3 Movement of the top surface of boards

The trials have provided the opportunity to investigate the possible movement restraint at the tops of boards provided by adhesives and to evaluate the effects of the different adhesive types. With regard to the nominal 130 mm and 133 mm wide flooring, matched boards were present in each panel. In addition to this sections of some boards from each panel were used to estimate the moisture content of the boards within the panels. To some extent it must be recognised that these sample boards would have experienced greater moisture uptake than the boards in the panel due to the greater exposed surface area. Even so these sample boards were totally unrestrained.

At each stage of the trial measurements were taken of the top cover widths of a sample board as well as their corresponding boards within each of the panels. The results were recorded for both the Tasmanian Oak flooring and Spotted Gum and are shown in Figures 22 and 23. In these figures 'SB' relates to the sample board, 'FL' refers to the flexible adhesive and 'SR' the semi rigid adhesive.

Figure 22 – Spotted Gum – Top cover width

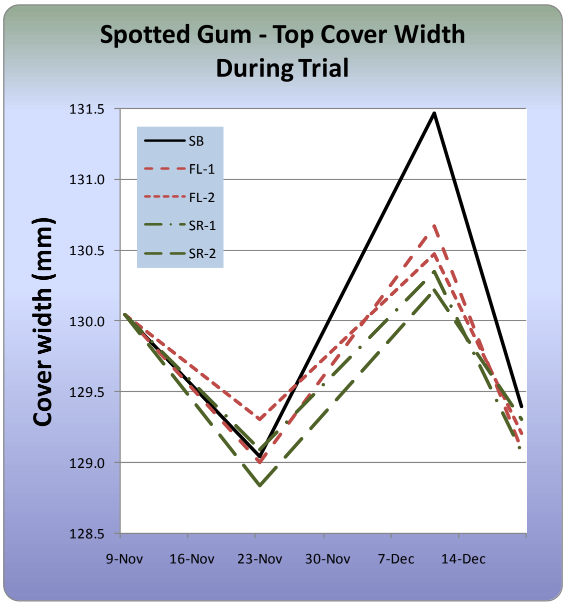
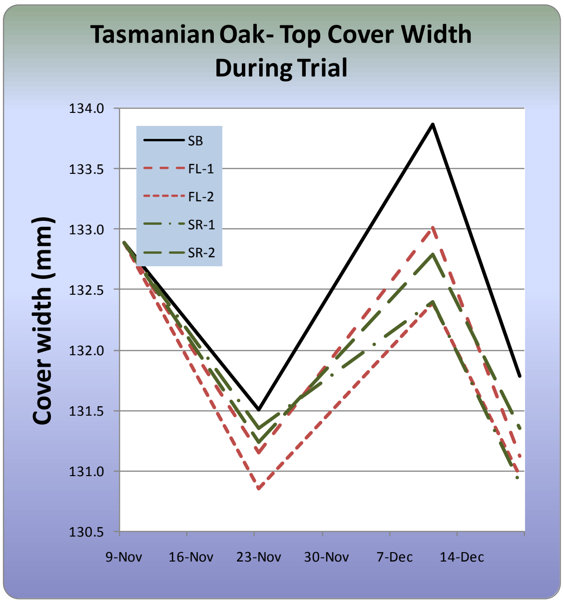


Figure 23 – Tasmanian Oak – Top cover width



It is evident from these graphs that the adhesive beneath the boards may be providing a small amount of restraint to the movement of the top edges of the boards but that for both Tasmanian Oak and Spotted Gum it was minimal. It is also apparent that the adhesive type has not had a significant effect.

Within the trial some boards had larger grooves machined into the lower surface and Figure 24 shows these boards (marked '–G') along with the boards above for the Tasmanian Oak. The result for the Spotted Gum was similar.

It is evident from Figure 24 that these larger grooves have no significant effect on the change in cover widths.

Figure 24 – Tasmanian Oak: Top cover width grooved boards (133 x 19 mm boards)

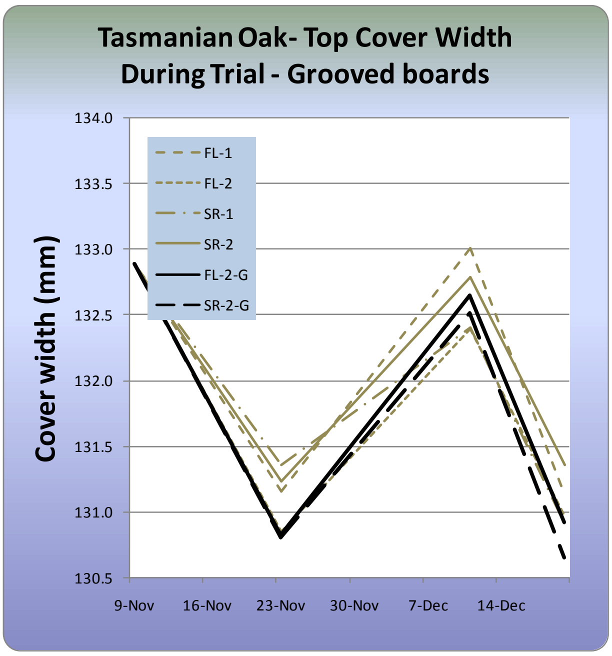
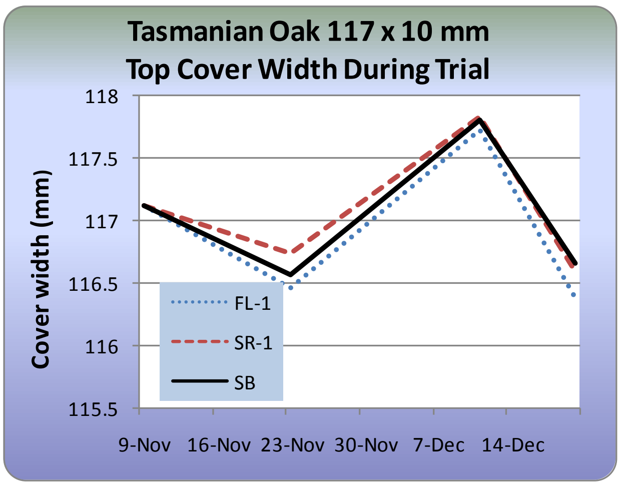


Figure 25 – Tasmanian Oak: Top cover width (117 x 10 mm)



As a further comparison measurements are provided for the 117 x 10 mm Tasmanian Oak. This flooring section is considered to have the least strength and therefore the most likely to experience influence from the adhesive. From Figure 25 it is again evident that the adhesive and adhesive type has little influence over movement occurring at the top of the boards.

In summary from the above it is considered that even though the adhesives can restrain overall expansion in a floor they have little influence over the movement in the exposed face of the board. Therefore other than the restraint provided by adhesives reducing overall floor expansion they can be expected to have no additional effect in preventing gapping that generally occurs when a floor experiences dry conditions, irrespective of the adhesive type.

9.0 Chamber testing and finite element analysis

9.1 Overview

In conjunction with the chamber trials finite element analysis (FEA) work has been undertaken by Ransi Devendra from Uroxsys. Outcomes from his reports are referred to in this section, however it is considered necessary that his reports, which accompany this report, be studied in order to gain an in depth knowledge of the interactions. Through his investigation work would progress to developing a model to predict the effect of floor board profile, on floor appearance, during moisture change in the flooring. From this the model could at some future date be applied as a screening method for profiles.

Finite element methods are used in the industry to investigate changes in physical dimensions of objects with complex shapes when subject to various loadings. Using this method, preliminary work as outlined above, has already investigated changes in dimension of various wood flooring board profiles during changes in their moisture content and the results compared favourably with chamber trials from previous research. These previous investigations indicated that this technique could be developed as a qualitative technique in screening of board profiles before further experimentation. However, the accuracy of its predictability will depend on input data such as material properties and boundary conditions. In the absence of accurate data it is possible to use approximate data to determine the trends in behaviors.

The FEA work associated with this project was as follows:-

- Characterizing the difference in performance, of high density to medium density flooring under floor expansion and cycling. Previous testing suggested that high density timbers were more prone to shearing the glue line and buckling off the sub-floor, whereas medium density timbers crush at board edges. The crushing causing the appearance of peaking at board edges.
- Establishing the ability of different adhesive types to prevent/reduce cupping of wide board flooring in both high and medium density hardwoods. The effect of the relief grooves in the lower surface of the boards was also to be investigated.
- Assessing adhesive strength and board thickness, density and effect of moisture gradient in wide thin overlay flooring to the propensity to split under shrinkage, stay level under expansion and not cup under moisture gradients.

With regard to this work Mr Devendra acknowledged the following limitations:-

Some difficulty existed and still exists in obtaining accurate material properties of wood and adhesives to use in the analysis. Algor software, to be used in the finite element analysis, had some material properties for selected wood species. Using this data it was possible to gain insight into the behavior. Also the material properties of adhesives had not yet been established but here again it was possible to get an idea of the behavior by using material properties of similar materials available in the software database or from the public domain.

In spite of these limitations the importance of this approach is considerable. It was shown above how very variable in nature timber can be and this was particularly so where the cupping present in the 133 x 19 mm Spotted Gum differed significantly between boards in the chamber trial. Due to the pronounced nature of this variability it can be difficult to assess what effects changes in say flooring thickness may be having. A major benefit of FEA is that it takes away the timbers variability and allows the many other variables to be individually considered.

The following will provide a summary of the outcomes from Mr Devendra's reports (In two stages) and include comments relating to the applicability of this method to outcomes from the chamber trial.

9.2 Finite Element Analysis - Stage 1 Outcomes

9.2.1 Cupping and Stresses

In this series of tests virtual board sizes of 70 x 12 mm, 70 x 19 mm, 140 x 12 mm and 140 x19 mm were assessed for cupping with shrinkage of the upper exposed surface (conditions of moisture loss) when fixed to a sub-floor with a high modulus (semi-rigid) adhesive. When boards cup in this manner the differences in the rates of shrinkage cause stress to develop within the board and this can lead to boards splitting. The results are summarized below.

Figure 26 – Cupping under shrinkage

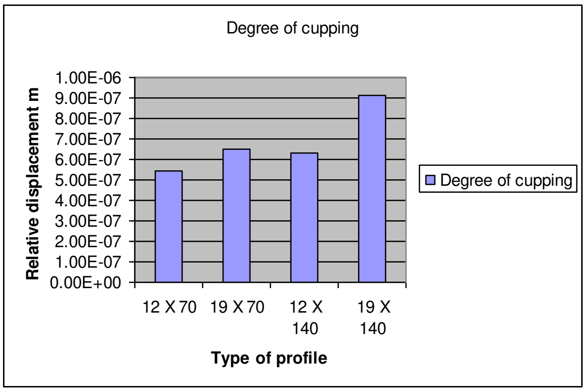
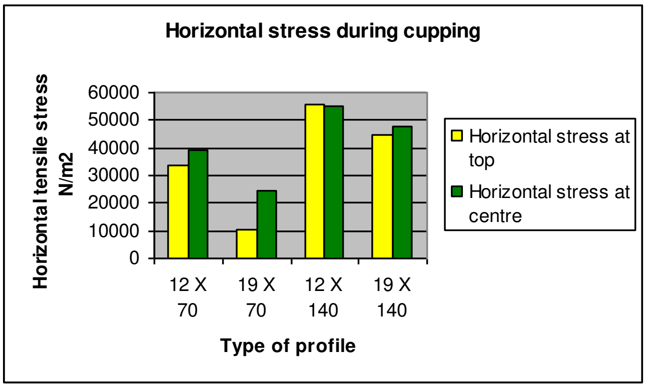


Figure 27 – Stresses under shrinkage



(Source: Uroxsys Ltd:- Report 1 – Investigation into cupping effect of solid wood floorboard using a finite element method)

These graphs outline the following two main principles:-

- The thicker and wider the board the more prone it is to cupping.
- The thinner and wider the board the more prone it is to splitting.

In the chamber trials both thin and thick boards cupped as also indicated by the FEA and certainly under initial dry conditions and during the dry conditions toward the end of the trial the cupping was more pronounced in the thicker material.

From a profile design perspective boards thinner than 19mm are going to less prone to cupping (under moisture loss) but if too thin they may split. This would also be species specific.

9.2.2 Effects of flexible and semi-rigid adhesives

The virtual board size for this test was 140 x 12 mm and it investigated the effect of adhesive rigidity on both cupping and stress.

Figure 28 – Effect of adhesive rigidity on cupping

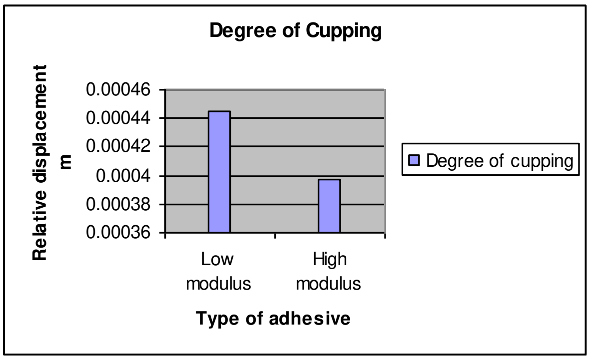
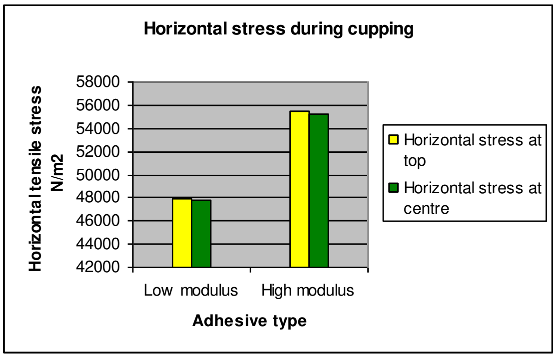


Figure 29 – Effect of adhesive rigidity on stress



(Source: Uroxsys Ltd: - Report 1 – Investigation into cupping effect of solid wood floorboard using a finite element method)

These graphs outline the following two main principles:-

- A more rigid adhesive reduces the degree of cupping however cupping could be noticeable with both.
- With the more rigid adhesive restraining the movement that is trying to occur, the board is more prone to splitting.

In the chamber trial there was nothing conclusive to indicate reduced cupping from the more rigid adhesives however this is one area where individual board properties dominated.

From a profile design perspective the FEA analysis suggests that performance of the floor in terms of possible splitting and degree of cupping will be influenced by the rigidity of the adhesive. Board thickness therefore needs to be sufficient to cater for both. In addition to this the analysis pointed out that the reaction force on the sub-floor would also be greater with the more rigid adhesives.

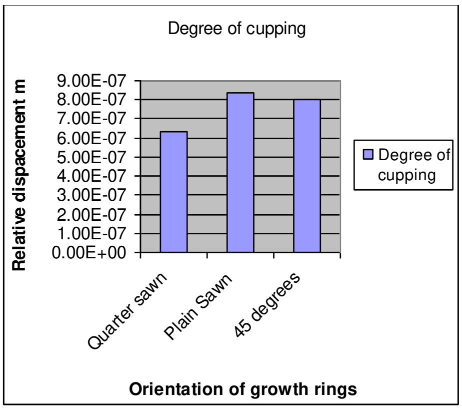
9.2.3 Effects of growth ring orientation

The virtual board size for this test was 140 x 12 mm and it investigated the effect of growth ring orientation on cupping. That is purely backsawn, purely quartersawn and transitional at 45 degrees.

This graph outlines the following main principle:-

- The degree of cupping varies between cutting pattern and expectedly the quartersawn was less. Greater stresses are also developed in backsawn material.

Figure 29 – Effect of adhesive rigidity on stress



(Source: Uroxsys Ltd:- Report 1 – Investigation into cupping effect of solid wood floorboard using a finite element method)

In the chamber trial the degree of cupping in the predominantly quartersawn Tasmanian Oak was considerably less than the predominantly backsawn Spotted Gum. The chamber trial inherently includes other effects such as density effects etc.

From a profile design perspective the FEA analysis suggests that relatively thin adhesive fixed quartersawn material with still have a tendency to cup under very dry conditions.

9.2.4 Effects of grooves in the bottom of the boards

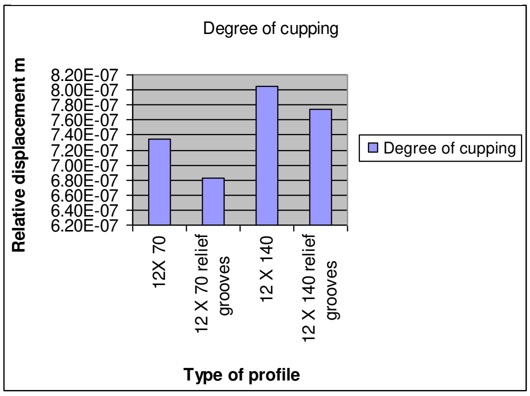
In this series of tests virtual board sizes of 70 x 12 mm and140 x 12 mm were assessed for cupping and stress.

This graph outlines the following principle:-

- Deep relief grooves have a tendency to reduce cupping and splitting however the effect is small.

In the chamber trials, although relating to thicker boards, relief grooves showed no clear benefit. In a practical sense they may however assist during laying providing a place for excess adhesive, particularly with the minor undulations present in slabs.

Figure 30 – Effect of adhesive rigidity on stress



(Source: Uroxsys Ltd:- Report 1 – Investigation into cupping effect of solid wood floorboard using a finite element method)

9.2.5 Effects of species density on cupping

With regard to these tests the timber properties available had densities of about 600 kg/m^3 as the lower density timber and 700 kg/m^3 for the higher density timber. Attempts to obtain data specific to a high density hardwood such as Spotted Gum was unsuccessful.

Figure 31 – Effect of density on cupping

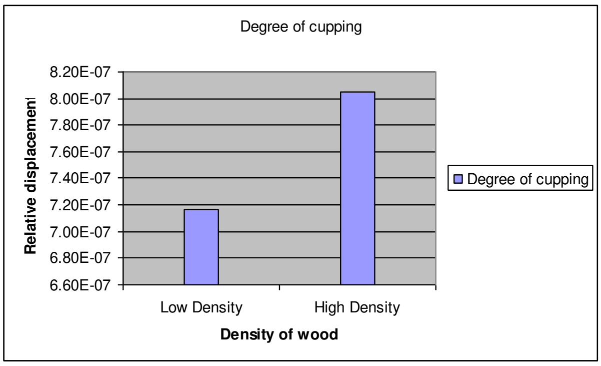
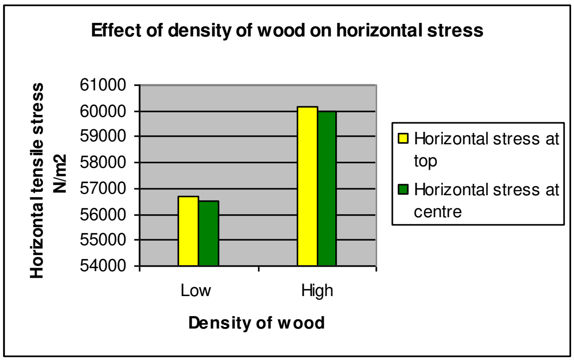


Figure 32 – Effect of density on stress



These graphs outline the following two main principles:-

- Lower density timbers when adhesive fixed are less prone to cupping.
- Lower stress is also developed in lower density timbers when they cup.

In the chamber trial the degree of cupping in the lower density Tasmanian Oak was considerably less than the higher density Spotted Gum. The chamber trial inherently includes other effects such as cutting pattern etc.

From a profile design perspective the FEA analysis indicates that the design principals applied to species of lower density are likely to differ from other species of higher density.

9.2 Finite Element Analysis - Stage 2 Outcomes

A further set of virtual tests were undertaken to refine some results of the above tests and to consider in more detail the moisture distribution through the boards particularly with adhesive of lower permeability on the lower surface of the board. In this series of virtual tests moisture content variation between humid and dry conditions was investigated

Awaiting information from Ransi

10.0 Optimising profile design

Past and present research which has included both chamber trials and finite element analysis on the behavior of timber floors is now providing us with a better understanding of what affects the performance of a timber floor under conditions of both higher and lower relative humidity. There are a number of main concepts and principals that we have been determined to date that should be considered when developing or reviewing current profiles and these are provided below.

1. Timber is very variable in nature and individual board characteristics can result in some boards acting differently to the majority of the others.
2. As such and particularly with the strength of the higher density hardwoods shape changes can occur and any fixing including adhesives will not prevent such changes from occurring.
3. There is nothing clear to suggest that any particular polyurethane adhesive provides significantly better performance in restricting movement even though the properties of polyurethane adhesives (including rigidity, strength and curing aspects) differ significantly between manufacturers.
4. Adhesives reduce the amount of swelling that occurs in a floor for both medium and high density hardwoods but it does not prevent movement.
5. Similarly, adhesives will not prevent hardwood boards from cupping under very dry conditions above the floor irrespective of the species.
6. When floors swell medium density hardwoods crush at their edges. When they re-dry under pressure their cover width becomes less when they return to moisture content they were at prior to the swelling.
7. Some boards of higher density under changes in environmental conditions appear more prone to cupping than lower density boards and backsawn boards are also more prone to cupping.
8. High density hardwoods do not crush under swelling to nearly the same degree and are more prone to peaking. Peaking is a pressure effect in the boards and the floor takes on a cupped appearance.
9. The adhesives in providing restraint to floor expansion may be contributing to the peaking and the degree of undercut or relief to the bottom face of the board is a major contributor.
10. Wider and thicker boards are more prone cupping under variable environmental conditions in floor fixed over sub-floors.
11. Thinner and narrower boards are less prone to cupping in an adhesive fixed floor under variable environmental conditions.
12. Thinner boards may be more prone to splitting under dry conditions.
13. Thinner profiles respond more quickly to moisture uptake and loss from the environment and are therefore more prone to movement and being more closely aligned to the room equilibrium moisture contents.
14. Adhesives that are more rigid provide some greater restraint to movement but only to a degree.
15. The groove pattern to the underside of the boards makes no appreciable difference to the movement experienced but physically may provide better keying and distribution of the adhesive.

From this it is clear that the design aspects of a board from the medium density Ash species should differ to that associated with the higher density hardwood. Similarly just because one profile design appears to be working well for one species type it does not mean that it will perform well for another species having significantly different properties.

10.1 Aspects of board design

When considering board design the aspects that need to be considered are:-

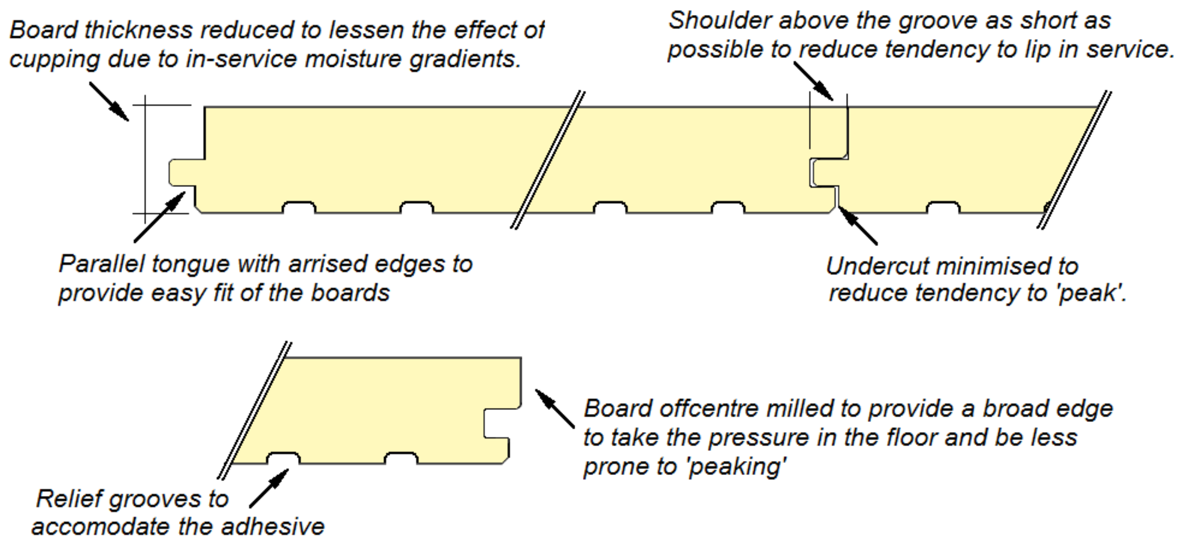
1. Board properties – Density, movement characteristics and cutting pattern etc.
2. Board manufacture – Moisture content and straightness etc
3. Profile properties – Cover width, thickness, undercut, position of tongue.
4. Installation method – Mechanical, adhesive or a mixed system.

In addition to this it must be considered what the market desires and what building constraints also dictate. It is apparent that there is a current trend toward wider board flooring and few floors are now installed with cover widths less than 80 mm and the practical maximum is about 180 mm from a resource perspective. Another trend is that fewer and fewer floors are being laid on joists with a moderate proportion being laid on battens. Hence the need for structural flooring that can span say 450mm has reduced and is still reducing. Even upper storey floors are not being laid direct to joists because workplace health and safety considerations necessitate a safe building platform. In many ways this is of benefit in that it ensures a greater stage of completion of the dwelling prior to the floor being installed and floor installation is being left more to those who specialize in laying timber floors, whether that is a particular builder or floor installation contractor. As such overlay flooring fixed to a sub-floor with adhesive is predominant in the market and in this market area thinner boards are often beneficial to meet constraints associated with a 2.4 m stud height. With board sizes within the envelope from a minimum of 80 x10 mm to a maximum of say 180 x 21mm it is evident that many profile sizes and designs are possible. As such many have been produced but it is only by considering the four aspects above that new products offering reliable performance can be developed.

10.2 Profile design for overlay flooring

The profile in Figure 33 applies some of the principles outlined above and comments on various aspects of the profile.

Figure 33 – Profile Design Principals



Peaking is an issue with standard profile boards as well as secret nail profile boards and invariably they are a centre milled profile. It is considered that in today's market an off centre milled profile with reduced undercut would alleviate many of the peaking issues. However, it must also be considered that with high density hardwoods it would be expected that greater lateral expansion would occur and other expansion issues would still be possible in more extreme conditions. Current recommendations indicate combined systems of mechanical fixing with beads of adhesive. Such a method permits 'easier' expansion of the floor than a full bed of adhesive and is perhaps well suited to profiles that are less prone to peaking. At this stage, although in current industry recommendations, such methods are not recognised on adhesive manufacturer datasheets.

For a number of years the performance of centre milled 80 x 12 mm flooring has been questioned. In earlier days the cupped appearance was put down to moisture gradient effects and it is only in more recent years that these effects have been recognised as being peaking. The typical 12 mm thick floor has approximately a 3.6 mm tongue and 4 mm edges above and below the tongue. It would not be uncommon for up to a millimeter to be sanded off the top of the board and this would result in all expansion pressure being resisted by 3 mm of timber about 8 mm above the substrate. As such it is particularly prone to pressure effects when floors expand. Provided below in Photos 12 and 13 is a section of the poorest performing 83 x 12 mm Spotted Gum center milled boards and a typical view of the 117 x 10mm off centre milled Tasmanian Oak, both at the end of the chamber trial. In addition to profile differences this also highlights the greater variability present in some higher density hardwoods and therefore the need for greater care in profile design.

Photo 12 – Poorly performing 83 x 12 mm Spotted Gum flooring

Photo 13 – Typical performance from the 117 x 10 mm Tasmanian Oak flooring

When boards are as thin as 10 mm, secret mechanical fixing is unlikely to be an option and full adhesive fix is required. In the Western Australian market such boards are adhesive fixed and then randomly top nailed into the concrete slab. This method does not occur in the eastern states where secret fixing into plywood or particleboard is more common. With these very thin boards and even those a little thicker, manufacturing processes need to ensure that bow, spring and twist are minimised and therefore additional care is necessary particularly with some species. When secret fixing is to be used the size of the tongue and its location are important and provision of an off centre mill profile will to some degree dictate the board thickness.

At the beginning of the trials it is doubtful that it would have been predicted that the 117 x 10 mm Tasmanian Oak would have performed at least as well and in many respects better than thicker Tasmanian Oak boards -135 x 13 mm or 133 x 19 mm. It was also clearly established that performance risks are higher with both wider and thicker Spotted Gum flooring as well as the 12 mm thick profile. With regard to the Spotted Gum the 80 x 19 mm flooring panel put in the chamber for comparative purpose performed better than other panels.

Note that it should not be misconstrued that the panels that performed more poorly would indicate that such product would not perform in many market applications. Clearly it does perform, however under the more extreme conditions associated with the chamber trial some products were more robust than others for a variety of reasons. This too is often why a product will perform satisfactorily in one location with a particular in-service environment but in another location with a different environment, it could perform quite differently.

Finally, it is considered that there is no single optimum profile, as consideration must be given to the species, manufacturing process and the installation methods in the markets where the product is to be installed. As such only general principles can be put forward and individual assessment is required.

11.0 Conclusions

The research has provided further insights into the interaction between timber flooring and the adhesives commonly used to fix wider board flooring. It has been established by previous research that adhesives restrict the natural expansion of timber floors however the degree and nature to which this occurs in both medium and high density hardwoods has been further quantified by this research. In addition to this the ability of different adhesives to reduce shrinkage and cupping has also been investigated.

The timber flooring used in the research varied from thin wide medium density hardwood through to a wide thick high density hardwood. The adhesives used covered both the flexible and semi-rigid polyurethane flooring adhesives.

From the work undertaken it was established that irrespective of the adhesive used, board movement occurred and irrespective of the board cross section or species, movement in terms of shrinkage gaps and cupping also occurred in all panels. The higher density Spotted Gum being predominantly backsawn exhibited greater movement and due to its high strength and the natural variability in properties between boards, it was able to dictate shape changes. The research showed that adhesives have limited ability to restrict movement on the top side of the board even with medium density hardwood down to 10 mm in thickness. Hence, although to a lesser degree than Spotted Gum, such boards would also shrink and cup.

Due to the nature of the trial it was difficult to assess whether the cupped appearance after the high humidity stage in the Spotted Gum was residual cupping from the initial low humidity stage or peaking from pressure effects. This may require some further work and what is of interest is whether the restriction in board expansion provided by the adhesives does in fact contribute to peaking due to increased pressure at board edges. This is an avenue of research that could be undertaken in the future.

In conjunction with this research, work was undertaken by Uroxsys Ltd (their full reposts attached) in developing a finite element model covering the interaction between timber flooring and adhesives. The finite element work has the benefit or removing the variability associated with timber and therefore the effects of other aspects can be more closely examined. The research undertaken here does however suggest that the properties of the timber particularly with the high density timbers tend to dictate shape changes and are therefore dominant.

The current finite element analysis work combined with that previously undertaken on peaking behavior provided some important insights into the behavior of the boards in the chamber trial and confirmed specific aspects that were observed. This included the propensity of the adhesive and mechanically fixed wider thicker boards to cup, particularly when environmental conditions vary. The model is still in the relatively early stages of development and requires further refinement. One difficulty was in obtaining accurate relevant property information for materials to be used it.

Concerning profile design the research established that there are many aspects that need to be considered and that there is no single optimum profile. Consideration must be given to the species type, capability of the manufacturing process and the installation methods that differ in the markets where products are installed. There was however a number of general principles outlined that should be considered by all manufacturers which provide guidance on aspects that they need to consider. It was however considered that in many instances changing to an off centre milled profile with minimal undercut would be of beneficial in reducing the occurrence of peaking, a pressure induced cupping that can occur with floor expansion after installation.