Blending efficiency Part A:

Solving the problem of chipout in laminated particleboard

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Abstract

The problem of chipout and poor machinability is a characteristic of particleboard laminated with decor papers and has been around since the inception of the product. This is particularly so with the use of high speed machining and cutting tools such as flatbed routers. The author, using innovative techniques including backscattered scanning electron microscopy, video light microscopy, contact angle goniometry and a newly developed technique of fingerprinting resin distribution down to an individual flake level, identified the problem. It was found to be caused by the excessive interfacial energy between the resin and flake surface resulting in uneven and poor resin distribution, especially on the larger flake particles in the surface layers. It was not as commonly believed related to flake geometry. It was caused when the high extractive content of certain pine species was subjected to high temperature drying, undergoing pyrolysis and converting the natural wood resins and extractives to fatty acids, resulting in flake surfaces of very low surface free energy. As a result, a novel solution was put in place which enabled the particular factory (using a southern pine species) whose future was under a cloud due to low market acceptance of existing panels to produce an acceptable product. The solution involved no capital expenditure and involved researching the fundamental operations of high speed blenders and the physics of wetting at an individual flake level. It resulted in the development and use of a specifically developed multi-phase wetting system Rezex A™. After implementation and consequent market acceptance of the product, the factory was given approval to invest millions of dollars in plant improvements. It now produces one of best quality products in the Australian market. As a result of this exercise, the company saved hundreds of thousands of dollars per month in the transportation of product from other factories in the group that had produced panels which had been more acceptable to the market place. What is described gives a mature product new life.

Introduction

It became evident from 1997 that laminated particleboard made from both presses at a particleboard plant in Northern Australia was significantly more prone to edge chip-out than laminated panels made at other plants in Australia and New Zealand which primarily use *Pinus radiata*. The problem became more apparent with the increasing use of CNC routers with double compression router bits, by some end users of the product. It also coincided with a change in the furnish mix from one primarily using Hoop pine *Araucaria cuninghamii*) to one primarily based on Slash pine *Pinus elliottii*. Slash pine has a very high resin and an extractive content of approximately 5 - 48% compared to radiata pine being 4% and hoop pine being 2% w/w on dry wood weight (Kahn 2000).

In order to satisfy the local market, laminated panels had to be transported from other factories in the south of Australia. This cost many hundreds of thousands of dollars per month, started around 1998 and continued until late 2007 at a total cost of many millions of dollars. The author was invited to take part in the project in 2007 after the company had spent over 8 years attempting to solve the problem. This had involved using experts from Australia and overseas and resulted in only one lead, a statistical relationship between the occurrence of chipout and the temperature of the inlet of the dryer (Cunningham 2003).

Prior to 2007 root cause analysis included; excessive grit in the surface flake leading to tool wear, surface density, flake geometry, proportion of late wood, precure, sanding through the hard zone, brittleness caused by high temperature drying, overcure of resin and incompatibility between the amino resins used and the natural wood chemistry.

Potential solutions that were tried were; buying new PAL blenders, installing air graders for grit removal (grit levels being <0.01% of surface flake weight), new larger capacity flake classification screens, varying resin loadings, increasing the MF resin coat on décor papers, using modified MF/PVA resins, use of surfactants, two pass sanding, varying board density, varying sand-off and manipulating the furnish mix by either adding or taking away fines and adding or taking away planer shaving. None were fully successful and the only treatments that had any positive effect albeit a minor ones were reducing the surface density of the board and reducing drier inlet temperatures.

The aim of this study was to determine the root cause of chipout that was affecting market acceptance of laminated HMR particleboard from this plant and to find and implement a solution. Chipout (*Figures 1 & 2*) occurs during machining of the edge of laminated particleboard, when chips of the laminated surface break from the machined edge. Up to 2007 the exact mode of failure had not been determined, i.e. whether it was the impregnated paper alone or whole or part particles of flake being removed from the freshly machined edge.

Materials and Methods

<u>Sample preparation and SEM imaging</u>

Edges of laminated 16mm HMR particleboard from the plant were taped using gaffer tape on the edges and routed using the Holzher spindle moulder that is the standard tool used by the company to measure chipout. This enabled the piece chipped out to be retained and matched with the void it left. The void was then gently removed from the remainder of the board using a scalpel.

Samples for SEM imaging were attached to 12mm aluminium SEM stubs using double-sided carbon tape. As wood is a poor conductor of electricity, samples were subjected to sputter coating with a 250 angstrom film of gold and palladium (60:40) in order to prevent ``charging" distortions of SEM images.

The samples were examined using a Cambridge Instruments S360 Stereoscan scanning electron microscope fitted with a high brightness lanthanum hexaboride (LaB_6) electron source. Backscattered electron images were obtained. These had the most contrast between the resin coated and uncoated particles. Sample magnifications varied according to the particular feature being imaged with the magnifications shown on the image along with a scale bar. All of the techniques used are fully detailed (Roberts 2004).

For light microscopy a Wild Photomakroskop M400 with a high-resolution digital camera was used to obtain images. Varying magnifications were used which are noted in each image caption. To highlight the presence or absence of resin on flake Safronin O dye was used which stains lignin. If resin was present on flake the Safronin O dye would not be able to stain the lignin. From this, an estimation of resin distribution on flake can be made. Full details of this are in Part B of this paper.

Results

<u>Identification of mode of failure</u>

Figures 1, 2 & 3 show details of the void left by chipout and the removed particle that caused it. The only resin evident is the saturating UF resin within the LPM paper. Of the 98 samples examined using SEM (both particle and void), only one sample showed any evidence of resination either on the chipout piece or chipout void (*Figure 4*). Note in the image that where there is resin present, the detail on the surface of the flake appears somewhat blurred and where there is no resin on the flake the surface detail can be seen with high clarity. The resin was only present on a small proportion of the total void. Apart from on this one sample, there was no resin on any of the flake either in the remaining hole or the chipout particle itself. What SEM analysis did not make clear however is whether the particles of flake actually broke apart as opposed to being chipped out whole. Both of these scenarios would result in little or no resin being apparent.

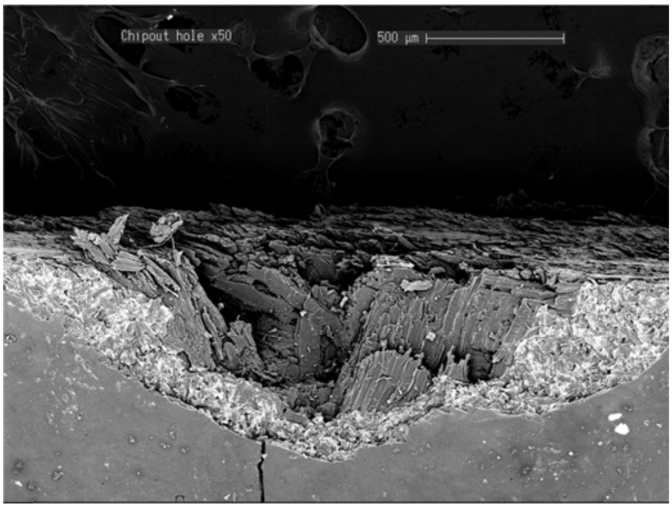


Figure 1 (x50) the void caused by chipout

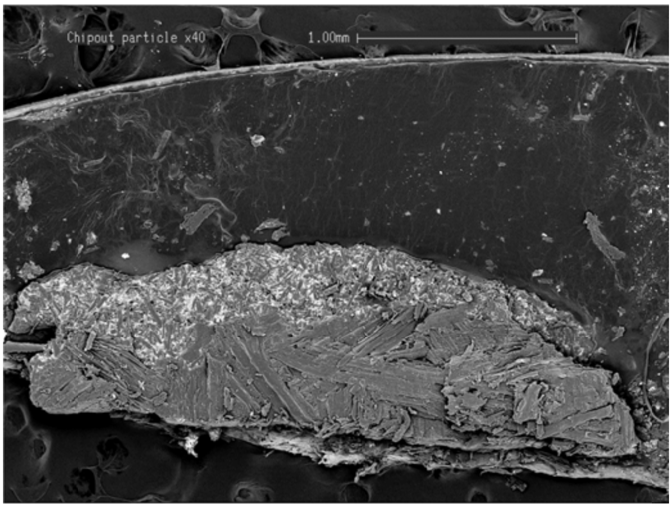


Figure 2 (x40) particle that was removed

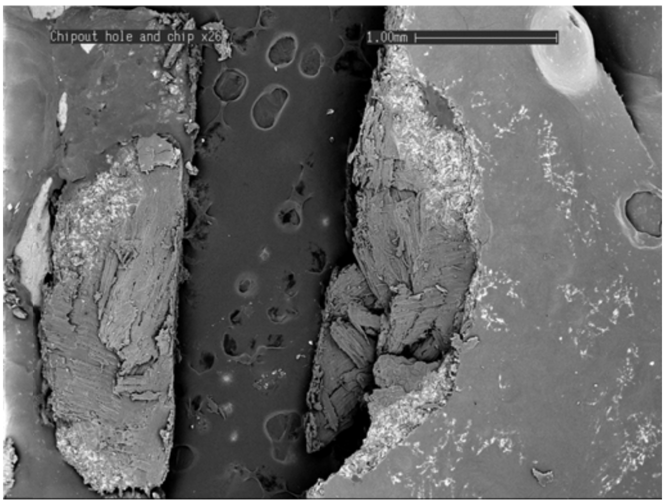


Figure 3 (x26) void and associated particle

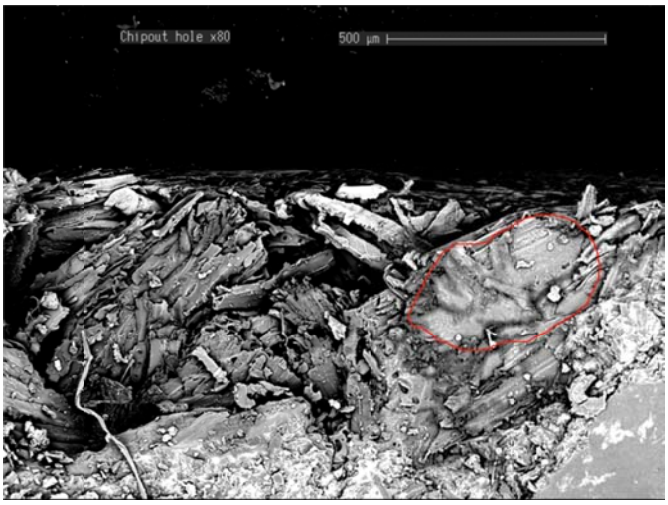


Figure 4 (x80) showing some resination in the chipout void (bounded by a red line)

Light microscopy images (*Figures 5 & 6*) show a chipout particle and associated void. Note that the area of paper is larger than the actual amount of wood particles removed. This was the case in every instance showing that even if a small particle was dislodged, a resultant much larger section of laminated paper was removed leaving a substantial void. In most cases the paper actually partially delaminated i.e. the melamine coated layer splits from the UF impregnated core. This is more clearly shown by SEM (*Figures 1-3*) where the impregnating UF resin is highlighted with backscattered SEM imaging. Light microscopy also showed that a chipout particle had evidence of sapstain fungus (*Figure 7*), and there being no corresponding sapstain fungus on the associated chipout void. This suggested that the particles were chipping out whole i.e. they were not actually splitting up.

The other aspect that was examined was the particle geometry of plant's surface flake. It can be seen from *Figures 8 & 9* that the aspect ratio of the flake was excellent and only very few "cubic" flakes were observed. Thus flake geometry as shown in the images was very good and would only enhance the ability of the flake to be maintained in the surface matrix and thus was not considered as part of the problem.

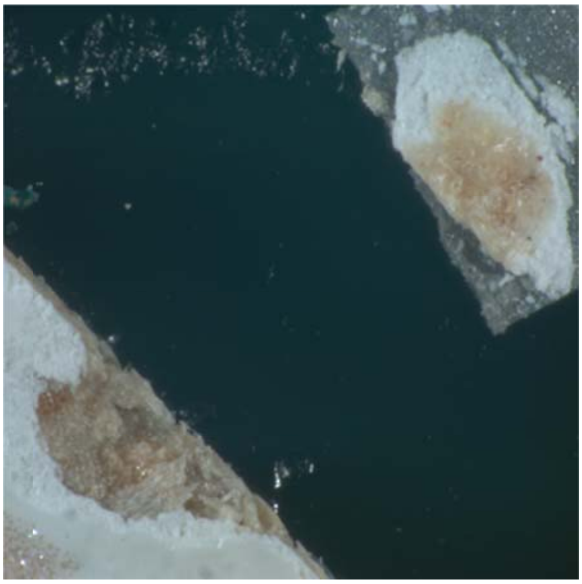


Figure 5 chipout particle and associated void

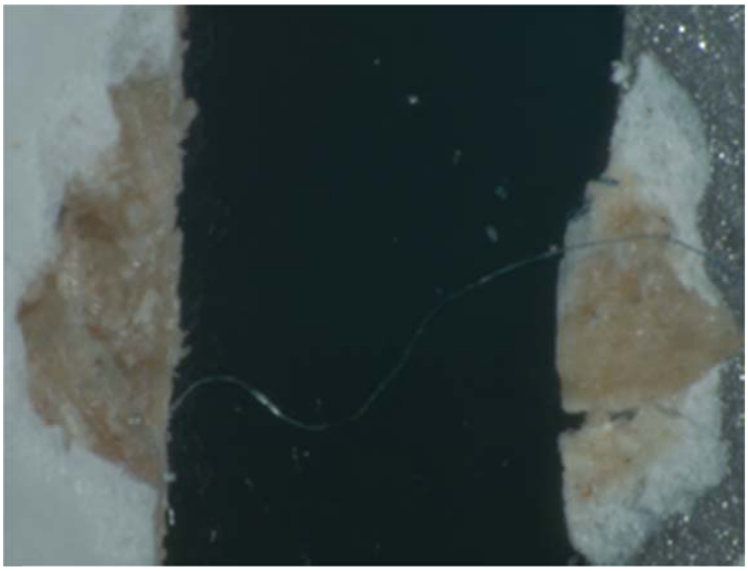


Figure 6 chipout particle and void

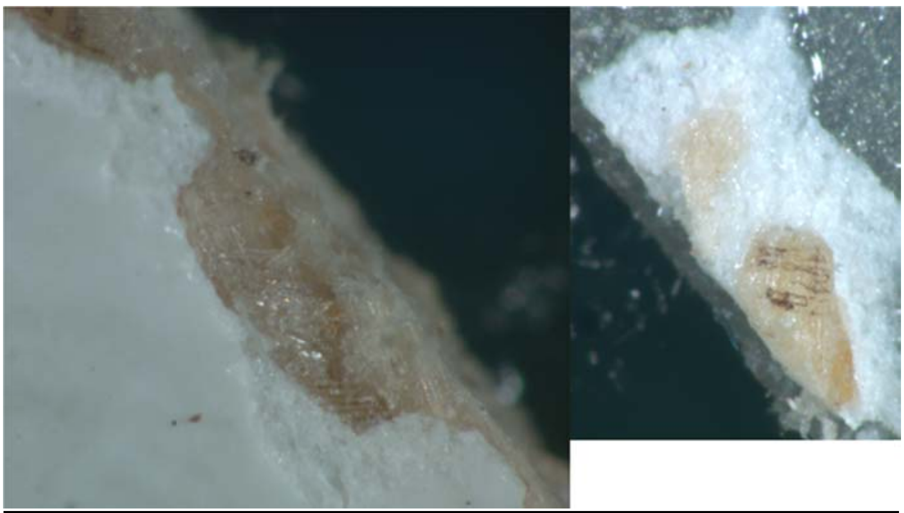


Figure 7 showing a chipout particle with sapstain fungus and associated void without

Figure 8 (x10) showing good particle geometry of the plant's surface flake

Figure 9 (x32) showing the high surface to volume (aspect) ratio

<u>Blending efficiency</u>

SEM and light microscopy showed that there was insufficient resin on both the chip-out particles as well as the remaining void. They also showed that the particles were not fracturing and that particle geometry was not a factor. A technique was developed to determine the distribution of resin on individual flake. This is detailed in Appendix 1 of Part B of this paper. The presence of red dye on the flake indicates a lack of resin. *Figures 10 - 13* show a heavy presence of red dye on all of the particles that had chipped out. This showed that there was very little if any resin on these particles fully explaining why they chipped out i.e. if particles were not strongly bound to each other in the surface, then machining would easily dislodge them, hence chip-out. The paper laminate did not hold poorly resinated particles in the panel.

A detailed examination of resin distribution was conducted on blended surface flake from the plant spreaders and the situation was exactly the same as with the chip-out particles themselves. There was very little flake that exhibited effective resin distribution. Of the thousands of samples of flake analysed from the plants spreaders i.e. ex blender, most of the larger surface flake showed primarily poor resination (*Figures 14-16*). *Figure 17* shows some small degree of resination however this degree of resination was rarely seen. Less than 5% of the flake was effectively resinated and >70% of the flake had no resin whatsoever. It thus became apparent that there was a serious blending efficiency issue with surface flake at this plant.

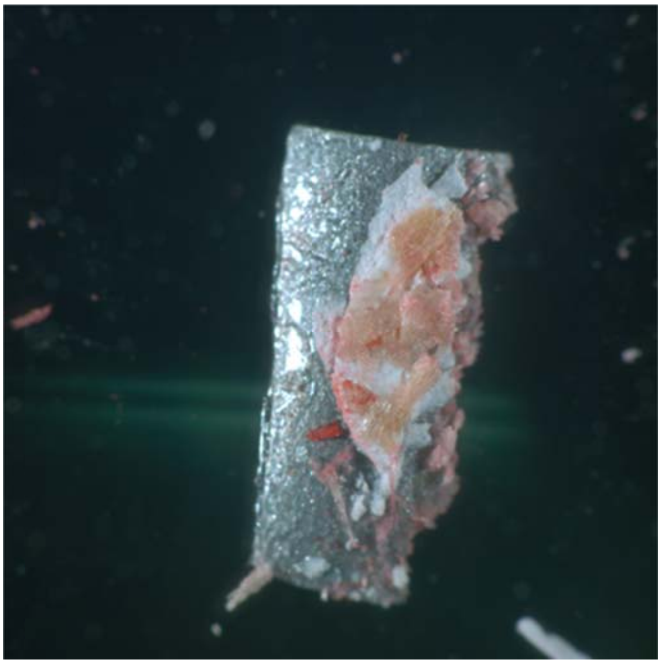


Figure 10 (x10) particle removed by chipout

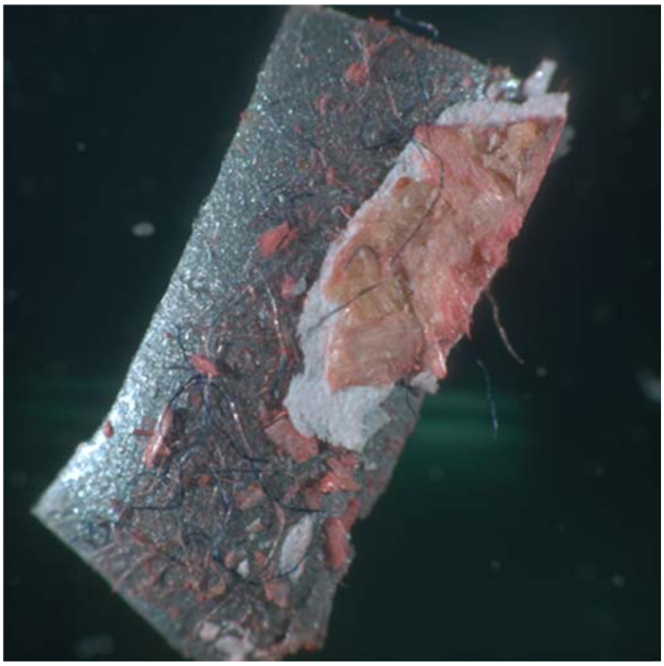


Figure 11 (x10) particle removed by chipout

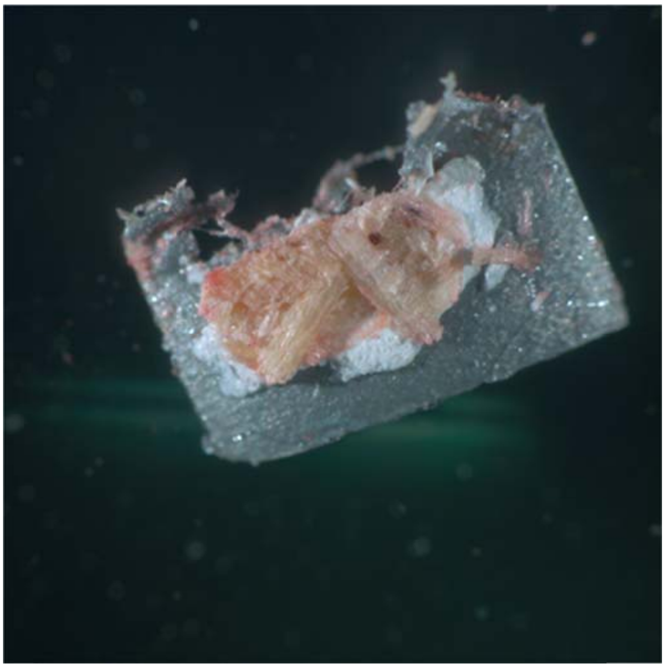


Figure 12 (x10) particle removed by chipout

Figure 32 (x10) particle removed by chipout

Note the presence of the Safronin O dye showing no resin distributed on the flake.

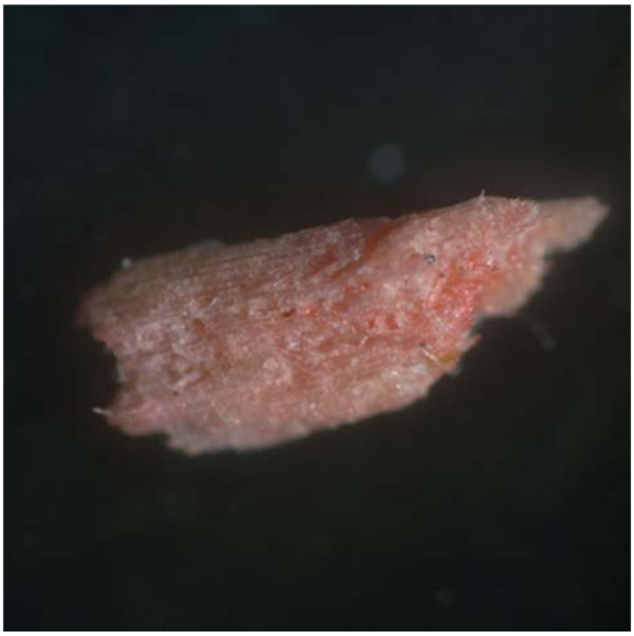


Figure 14 (x20) poorly blended surface flake as can be seen by the amount of Safronin O dye present

Figure 15 (x20) very poorly blended surface flake

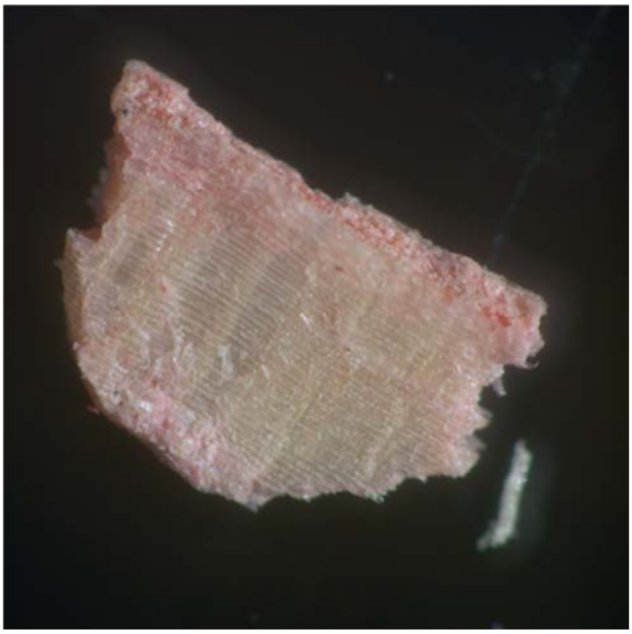


Figure 16 (x20) poorly blended surface flake

Figure 17 (x20) well blended surface flake note much less Safronin O dye on flake

<u>Wettability of flake</u>

Before 1997 board made with hoop pine surface was of good quality having no machinability problems as was the case with board made with radiate pine. However board made after 1997 with predominantly slash pine surface performed very poorly when machined on flat bed routers. There appeared to be a species effect which was thought to relate to how effectively the species blend. Blending is a function of wetting and is related to the surface free energy of the flake and the surface tension of the liquid, i.e. the interfacial energy between the two. The relative surface free energy of each species was estimated by contact angle determination using a KSV Contact Angle Goniometer. The following images show how droplets of resin on contact wet the different species used by the company:

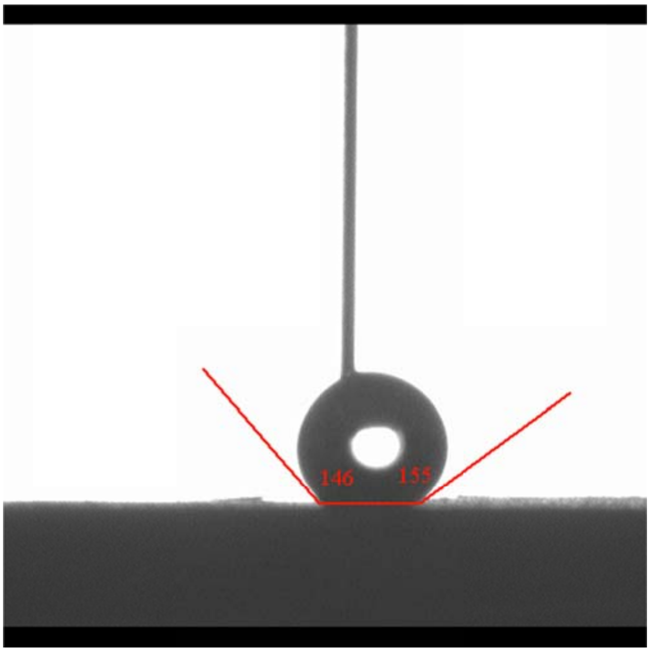


Figure 18 Goniometry image of resin drop on block of slash pine contact angle 150°

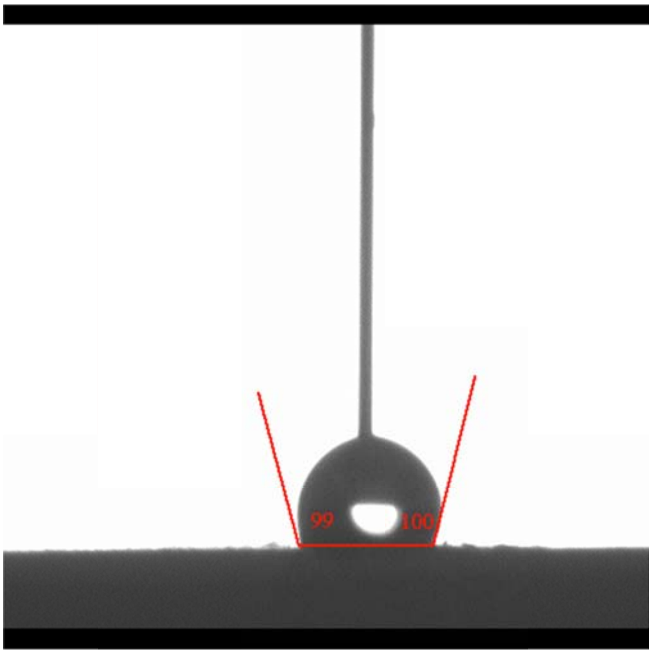


Figure 19 Goniometry image of resin drop on block of radiata pine contact angle 100°

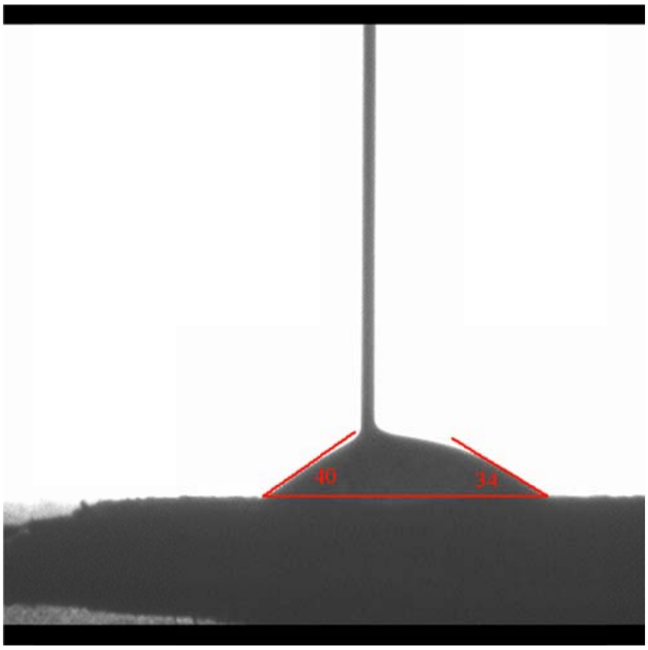


Figure 20 Goniometry image of resin drop on block of hoop pine contact angle 36°

It is easy to see from *Figures 18 - 20* that Slash pine is a non-wetting species whereas Hoop wets very well, explaining the reason why board made with Hoop pine machined well. This was due to the very high resin content in Slash pine (5-48%), which under high temperature drying converted to fatty acids on the surface of the flake which became very hydrophobic. This would explain the finding by Cunningham 2003 that reduced drier temperatures resulted in better machinability properties because there was a lower level of conversion of wood resins in the Slash pine to fatty acids through pyrolysis (Khan 2000). Therefore the chipout problem was caused by poor resination of surface flake, due to low surface free energy of slash pine after high temperature drying and high surface tension of resin mix (high interfacial energy). Viscosity of the resin mix obviously has an effect however it would be the same for all species. Simply adding water to resins is not a good solution as this may reduce viscosity but does nothing to change the surface tension. It also slows cure time down due to the increased level of steam that has to be removed from the curing panel during pressing.

Improving the wettability of Slash pine, lab studies

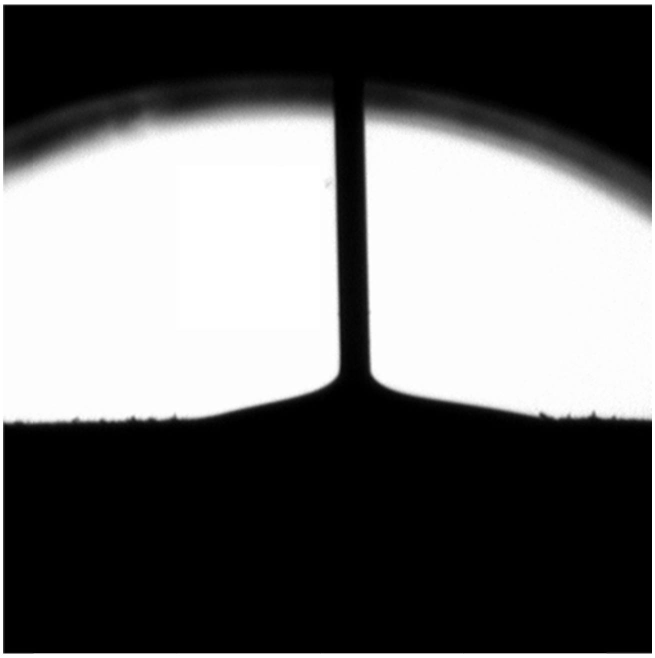
There were two ways to improve the wettability of Slash pine and in doing so affecting how well it blended. Increase the surface free energy of flake by increasing the flake moisture content or by decreasing the surface tension of the resin mix by adding compatible chemicals either charged or non-charged surfactants or other wetting agents. A large number of commercially available and development surfactants were firstly tested for compatibility and stability with the MUF resins used at this plant and subsequently used in full scale plant trials.

The best of these were a number of combinations of concentrations of Teric N9 an alkyl nonylphenol ethoxylate non-ionic surfactant sourced from Huntsman Chemicals added to water to pre-wet the flake and in so doing increasing the surface free energy of the wood and to the resin to reduce it’s surface tension. A combination of 0.5% N9 added to the water with 1.0% N9 added to the resin proved to be the best combination as determined by measuring contact angle. However when dryer temperatures were increased during the wet season and when flake demand was high this solution was unsatisfactory. This type of surfactant is also considered to be an environmental risk in Australia due to its toxic properties in aquatic environments. As a result it is now being phased out of use.

A purposely developed multi-phase wetting system Rezex A™, was introduced to the surface resin mix only at an equivalent rate of 0.4% on dry wood weight. This was developed at the Australian National University and is now being manufactured by Oxford Technologies Australia in Melbourne. *Figures 21 & 22* show the effect i.e. reducing the contact angle of resin from above 140° to less than 20°.

Implementation of Solution

Laminated boards were tested on a Morbidelli Author 600X flatbed router at a factory of a major purchaser of laminated panels from this plant, New cutters being used for each trial. The spindle speed was 18,000 rpm with a feed speed of 30 m/min. Each board is machined for 100 lineal metres, with the chipout being measured every 4th, 8th, 12th, 15th, 20th 25th 30th up to 60th boards i.e. potentially up to 6000 lineal metres. The board machined as well if not better than any board made with radiata pine. Customers in this very large market now prefer this plant’s board over any other in the market place.



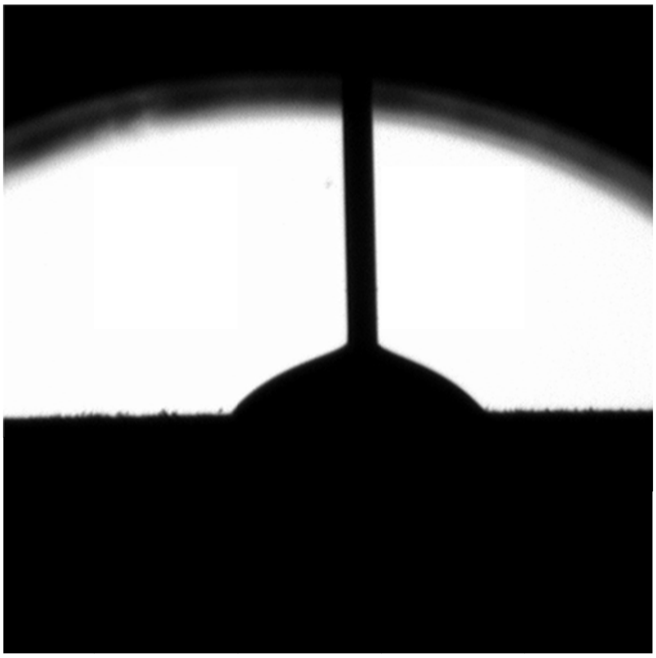


Figure 21 showing the contact angle of resin on Slash Pine with 0.2%

Figure 22 same as Figure 21, compare with Figure 18

Conclusion

The aim of this study was twofold; firstly to identify the cause of chipout, and secondly to implement a solution. One cannot effectively solve a problem without identifying its true cause. This was achieved using techniques, equipment and expertise that was and is not available to most panels manufacturers and involved detailed research at the Australian National University which is the top research university in Australia and also one of the leading universities worldwide. The problem was found to be insufficient resin distribution over larger particles in the surface layers. This was caused by very high interfacial energy between the surface of the flake and the resin mix primarily due to the very low surface free energy of the flake caused by pyrolysis of the natural wood extractives during high temperature drying.

The solution involved analysing dozens of commercially available surfactants and finally developing a multi-phase wetting system Rezex A™.

Rezex A™ was implemented in the factory and laminated panels produced from this factory are now comparable to the best machining panels in Australia and are the preferred panels in the dynamic northern Australian market. The savings to the company over the period have been many millions of dollars in transport costs which enabled a large investment in a new equipment for the plant. What has been described involves no capital expenditure yet gives a mature product new life, especially particleboard made with highly resinous timber.

Patents have been applied for Rezex A™ and the applications.

References

Part B: Core blending efficiency and how to improve it