Identification of the Parameters which Influence Panel Flatness and their Control

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Abstract

Ayres Composite Panels produce AYRLITE® 2022 panels mainly for the marine industry. The panels are manufactured in steam heated presses. The panel core is hexagonal aluminium honeycomb, faced on each side with sheet aluminium. The dimensions of the finished panels are 2400mm _ 1200mm _ specified thickness. A problem with manufacture occurs intermittently where the panels warp or bow. The reason for the bowing is unknown but transient heat flow issues seem to be a major contributing factor. The bowing interferes with production and is costly as the bowed panels can not be sold. This project was initiated to identify, and propose control methods for parameters that influence panel flatness. No previous formal investigations have been undertaken to address this problem. Although much of the research and finding are confidential this paper illustrates much of the methodology for the investigation and testing. The investigation and results show that a temperature difference through and across a panel during manufacture can occur and may induce a panel to bow when returned to ambient room temperature. The investigation has recommend several issues to be considered such as a review of the control system, maintenance to ensure possible deposits and corrosion in serpentines and piping systems are removed and systems be employed to prevent reoccurring deposition and corrosion.

1.0 Introduction

Ayres Composite Panels produce AYRLITE® 2022 panels for use in the marine industry. The panels are manufactured in steam heated presses. The panel core is 6mm hexagonal strain hardened aluminium honeycomb with a web thickness of 50_m faced on each side with sheet aluminium. The available thicknesses of the aluminium faced laminate, referred to as skins, are 0.3mm, 0.5mm and 1mm. Finished panel thicknesses are 6mm, 10mm, 20mm and 30mm. Thicknesses can also be custom ordered. The dimensions of the finished panels are 2400mm _ 1200mm.

Several years ago, after routine manufacturing maintenance to the presses performed by contractors, the presses started to produce bowed panels. The manufacturing parameters influencing panel flatness that were actually altered are unknown. After much guesswork and adjustment the problem has almost been resolved. However, bowed panels still occur intermittently. This is a costly occurrence as the bowed panels cannot be sold and disrupt production flow.

This project was initiated to identify, investigate and recommend control methods for parameters influencing panel flatness. No formal investigations into this problem have been undertaken in the past.

Unfortunately during the course of the project it is highly unlikely that all potential parameters influencing panel flatness would be identified. However the student and academic supervisor are confident that the most significant issues have been investigated.

Initial investigations into the problem including interviews with management and staff identified several issues warranting further investigation. The thermal coefficient of aluminium is relatively large $23\_10^{-6}/°C$. If when the adhesive is bonding the skins to the core, the temperature of each skin is different, upon cooling the length of one skin attached to the core will differ in length from the other skin. This may cause a panel to bow. Also the control system for the heating cycle has little feed back and the control system for the cooling cycle is a feed forward system, this indicates that a temperature variation between platens in the press may exist.

A series of tests were developed to map the transient heat flow and the temperature profile of the skin and web of a panel through the heating and cooling cycles. The ideal cycle would heat and cool both top and bottom skins evenly at the same temperature and at the same rate of temperature change. The results differed somewhat from the ideal cycle. A temperature difference was found across and between the skins indicating that if the temperature difference was too great, particularly through the thickness of the panel, it may bow.

A more thorough analysis of the press configuration and control system has been undertaken which will result in recommendations for maintenance and modifications to the manufacturing equipment.

Due to the confidential nature of this project only limited results and findings can be disclosed.

2.0 Background

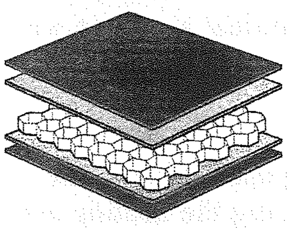
The project was constrained to the AYRLITE® 2022 panels. These panels are used mainly for doors, cabin linings, furniture, partitions, ceilings, C-class bulkheads, etc. Other industries such as rail and construction are also showing interest in the product.

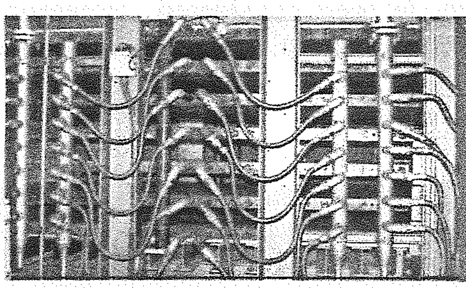
The panels are manufactured in steam heated presses. Each press has 6 apertures, referred to as daylights. Each platen is made of mild steel, 2500mm long, 1300mm wide and 50mm thick. A serpentine is bored into each half of the platen and used for heating and cooling fluid flow. The serpentines start at the corners of one side of the platen and terminate in the middle of the same side. The top of the top platen and the bottom of the bottom platen are both insulated to reduce heat loss.

Assembled by hand, an aluminium skin is positioned on the work surface and is covered by a layer of adhesive, the core is placed on the bottom skin and another aluminium skin covered with a layer of adhesive is placed on top of the core.

At the beginning of each cycle, one un-bonded panel is positioned into each daylight. Hydraulic rams raise the bottom platen bringing all of the panels under pressure. Once under pressure the heating cycle commences. When the desired temperature is reached, the press is maintained at this temperature for a preset time which assists the bonding process. The cooling cycle then lowers the panel temperature to one suitable for safe handling. The press is lowered, panels removed, the next batch of panels inserted and the process starts again.

The definition of a bowed panel is one that has more than a 3mm to 4mm variation along its length or width.





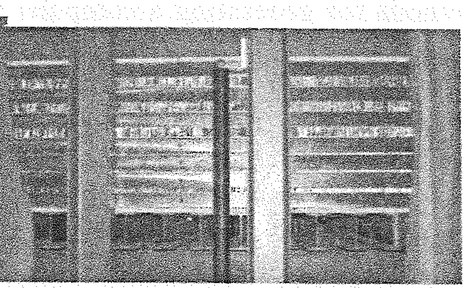


Figure 1: Panel exploded view. Figure 2: Steam Press, daylights open. Figure 3: Steam press closed with panels.

With no previously documented work on the problem and the specific problem/s unknown, the staff and management at Ayres Composite Panels were a wealth of information.

The main points were:

- The occurrence of bowed panels does not seem to be reproducible and seems to be a random event.
- Bowing tends to affect the smaller thicknesses of panels (6mm and 10mm). The larger thicknesses (20mm and 30mm) rarely bow, however bowing of the larger thicknesses does occur sometimes.
- The skin thickness or dissimilar skin thickness does not seem to influence panel flatness.
- The grade of aluminum skin or core manufacturer does not seem to influence panel flatness.
- Both presses are identical in design. However, adjustable parameters may differ.

The main points from the student's initial investigation were:

- Aluminium has a large coefficient of thermal expansion 23_10^{-6}/°C. If the temperature difference between the top and bottom skins at bonding were large enough, the panel may bow when returning to room temperature. This would be the result of one skin expanding more during the heating part of the cycle than the other, the skins bonding to the core and then contracting upon cooling. The area of skin bonded to the core during heating would be equal, however when returned to room temperature the area of one skin bonded to the core would be less than the other. The induced stress in the skin would be greatest along the length, if the induced stress was large enough the panel may bow.
- The aluminium used in panel manufacture comes off large rolls. As the roll is used the curvature increases. The skins usually flatten out due to their own mass, however a pre-stressed/strained state of the skin prior to manufacture does occur. If the skins are not positioned such that the pre-stresses and strains are opposite, this may be an additional factor influencing panel flatness.
- Although temperature tests have been conducted on the exterior of the platens to asses the temperature cycle of each platen, no tests have been conducted to asses the temperature profile on the surface of the platens or panels during the heating and cooling cycle.
- The edges of the presses are exposed to the ambient room air. This will allow loss of convective and radiant heat.
- The control system for heating is a hunting system and for cooling it is a feed forward system.
- There is little feedback for the heating control system.

What seemed to be the most important issue regarding panel flatness is that both top and bottom skins of the panel need to heat and cool at the same rate. This implies that to ensure panel flatness, both top and bottom skins should have identical surface temperature profiles throughout the cycle, particularly when the adhesive bonds the core to the skin.

Methods for generating a computer model were considered. However the actual temperatures being generated by the press were of great interest to the client and an empirical approach was taken.

Experiments were developed to:

- Map the temperature profiles of the panel skin surface during the heating and cooling cycle.
- Discover if a temperature difference occurred between panel skins during the heating and cooling cycle.
- Assess the data and to determine if any other factors may be influencing panel flatness.
- Devise and recommend ways of controlling identified parameters influencing panel flatness.

When methods for constructing the test equipment were being developed, methods of heat transfer needed to be considered. Heat or thermal energy transfer is achieved in one of three ways. Conduction, convection or radiation. When considering the heat transfer through a panel over the heating and cooling cycle, conduction through the aluminium skins and web is the most significant factor. Conduction or possibly convection would be occurring within the air trapped in each cell (the cells are perforated to allow expansion and contraction of the trapped air) and a small amount of radiant heat transfer may pass from one skin to the other at various stages. The edges of the panel and platen are exposed to the room and would lose heat through convective and radiation heat transfer.

When considering transient heat flow measurement, alterations to the shape (such as punching holes in the web) of an object or any additional thermal mass (such as thermocouples, thermocouple wire and thermal adhesive) will alter the heat flow characteristics of that system. When applying these modifications to a system they must be considered when designing test equipment and also when reviewing results.

For this reason 0.2mm Teflon coated type K twin twisted thermocouple wire was selected. This wire had the smallest mass of any economically available wire. Also the holes required to run each pair of wires through the core were the smallest possible. This also ensured that the wire was not damaged between the skin and the web of the core when pressure was applied to the panel by the press and the thermal characteristics of the panel were altered as little as possible.

3.0 Method for Mapping the Skin Temperature Profile

Although the temperature profile could be approximated theoretically across the surface of the test panel, the actual profile was not known. Therefore a blanket approach was used for the first test panel.

The thermocouple data acquisition equipment available for the project had 42 available channels. A grid of approximately 300mm _ 350mm was used across the first test panel for thermocouple positioning. This allowed 40 thermocouple positions. The grid comprised 8 thermocouples lengthwise and 5 width wise.

This test panel was constructed from a 5mm core with 0.5mm skins. The core was bonded to one skin only prior to thermocouple installation. This allowed thermocouples to be easily installed and replaced if required. To ensure good thermal contact between the thermocouple and the skin, the adhesive at the bottom of each cell where a thermocouple was to be attached was removed. This was achieved with a small scraper fashioned from a piece of fencing wire, heat treated and sharpened.

The small holes were individually punched in the web with a modified pair of pointed nose pliers. Each pair of wires was then individually threaded through the core to the appropriate cell. Small surgical forceps were very useful for this task.

The wires were installed prior to welding the thermocouple. If a thermocouple was welded prior to threading the wires through the core it would usually separate from the wire.

To make the thermocouples, the ends of the wires were stripped by approximately 10mm, twisted, trimmed and welded into a thermocouple with an oxygen/acetylene torch. The size of each thermocouple was approximately 1mm in diameter. Each thermocouple was then tested to ensure that it was working prior to attachment. Each set of wires was labelled corresponding to its position for data collection purposes. Attachment of the thermocouples to the skin was achieved with a thermally conductive adhesive. This adhesive is a two part epoxy resin which is 60% silver powder. Its thermal conduction is better than 7.5kW/m°C. The amount of thermal adhesive used per thermocouple was kept to minimum to ensure minimal alteration to the heat flow.

To ensure that the acquired data was accurate, all wires connecting the test panel to the data acquisition equipment were kept as short as possible and the wire harnesses were wrapped in aluminium foil and earthed when performing tests to shield them from electrical noise.

The panel was placed into the desired daylight, wired to the data acquisition equipment, press closed and the heating and cooling cycle started.

4.0 Method for Mapping the Temperature Variation Between Skins

Regions of interest on the surface of the skin had been refined from the data collected from the first series of tests. These regions were the centre, corners and edges of the panel. Thermocouples were now positioned on the top, bottom and middle of the web as well as both skins. To determine if any measurable heat flow through the core could be detected, a 19mm core with 0.5mm skins was used.

A 19mm core was also the thickest core that provided reasonable access for removal of adhesive at the bottom of the core cells.

Similar in construction to the first panel the core was bonded to one skin only prior to thermocouple installation. The panel was cut into 3 sections of approximately equal length. The regions of interest were well away from theses cut and would not have interfered with the heat flow characteristics at the points of data collection. This allowed for shorter wire runs and was convenient when attaching the top skin thermocouples.

The layer of adhesive at the bottom of the cells of interest was removed using a small engraving tool-bit. Thermocouple wires were threaded through the web of the core prior to welding the thermocouples through small punched holes. The thermocouples were attached to the skin and web using the thermally conductive adhesive.

The method for attaching the top thermocouples was the most difficult. These were left sticking out of the top of the cell by a few millimetres using the wire's stiffness as a spring. The adhesive on the top skin was not applied to the surface where the top thermocouples were to be attached. The top skin was placed on the work surface with the adhesive facing upwards. The other part of the panel was sitting adjacent with the top thermocouples pointing up. Thermally conductive adhesive was applied to the top thermocouples and the panel flipped over with the thermocouples now facing downward then placed onto the top skin. Weights were placed on top of the bottom side of the panel and an epoxy adhesive was used to bond the top skin to the core in several places around the edge. This ensured that the top skin would not move around while being moved to the press for bonding and the top thermocouples would not be damaged or lose their attachment.

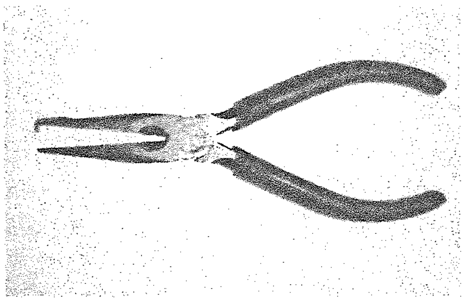


Figure 4: Modified pointed nose pliers.

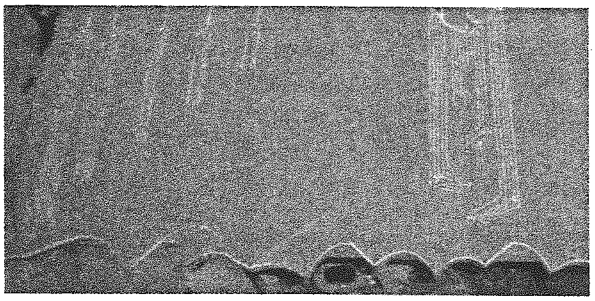


Figure 5: The second test panel showing the wire runs.

5.0 Experimental Data

Data from the first series of tests showed a relatively even rate of heating and cooling from the ends to the middle of the panel. One interesting phenomenon the data indicated was that a distinct difference in the heating profile of one side of a platen to the other can occur. Figures 6 and 7 illustrate this phenomenon. The data has been normalized to show the trend but not the specific time and temperature. Surface plots of the temperature profile also showed the edges of the panel were cooler than the middle once the press was up to temperature.

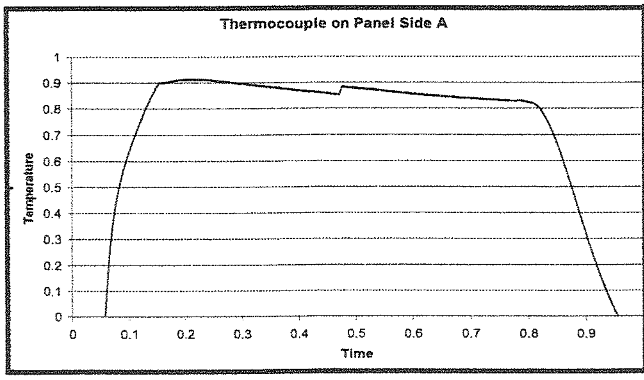


Figure 6: Heating & Cooling Cycle of Platen side A.

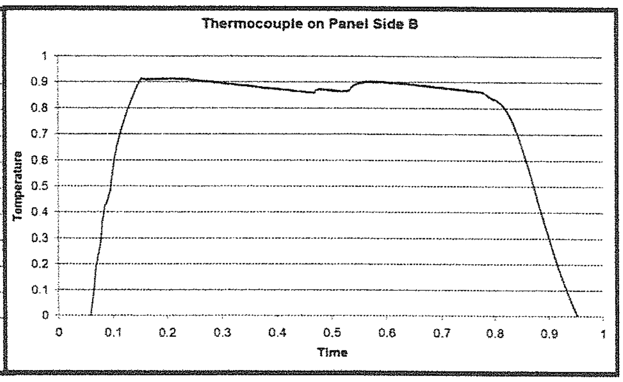


Figure 7: Heating & Cooling cycle of Platen side B

Data from the second series of tests focused on the corners, edges and centre of the panel through the web of the core. The tests showed that a definite temperature difference between skins can occur during manufacture. Figure 8 shows an example of this temperature profile. This data has also been normalized.

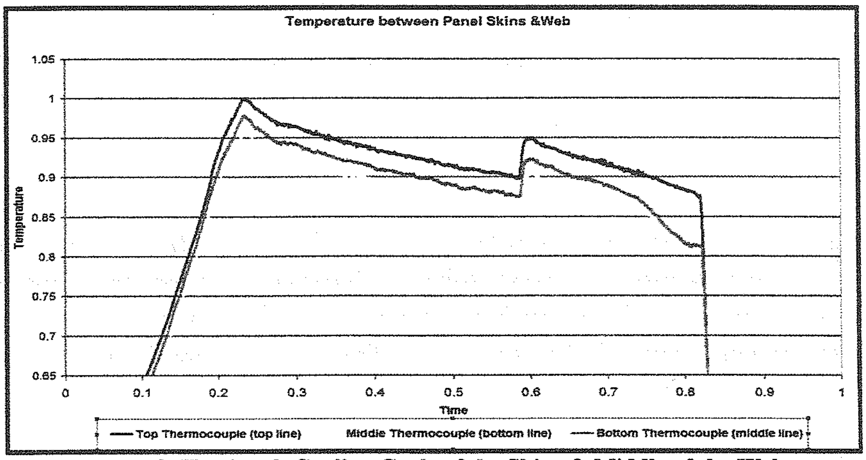


Figure 8: Heating & Cooling Cycle of the Skins & Middle of the Web

6.0 Discussion

The fact that bowing tends to occur mainly in the smaller thicknesses of panel is consistent with composite beam theory. Basically, as the core increases in thickness, the skins become further away from the neutral axis of the beam. The skins act somewhat like the flanges of an I-beam. As the core increases in thickness, the panel's strength and resistance to bending also increases.

The fact that bowed panels were not a reproducible event and seemed to be random indicated that one or more of the significant parameters were transient and may not be discovered.

Although an empirical method was used during the project much thought and research was spent on a computer generated model. This research greatly helped in the understanding of what was physically happening with the heat transfer through the manufacturing process.

Developing methods for the construction of the test panels was very challenging. The removal of the adhesive at the bottom of the web without damaging the web took many attempts to perfect. The wire tool was effective in the 5mm thick web, but useless in the 19mm web. The engraving bit was very good at removing the adhesive, however extreme care needed to be taken or it would rip through several cells.

All of the data was processed with Excel. Each test returned a matrix with the number of thermocouples used by approximately 40,000 cells. The Macros in Excel were very useful when processing these vast work sheets.

The processed data from the tests indicated several issues previously unknown. The possible variation between serpentines that can occur during heating and cooling suggests throttling of some kind may be occurring in the serpentines. The difference between skin temperatures may also imply throttling.

The presses are 10 years old and have many cycles of steam and water through them every day. It is possible that at some positions in the platens deposits have built up and are causing the throttling. Also the platens are made of mild steel and may have corroded sufficiently inside the serpentines to add to these deposits. If these deposits come loose and travel through the serpentine, get caught by deposit build ups further along the serpentine and cause throttling for one or two cycles then get washed away, this may account for the intermittent occurrence of bowed panels.

The cooler edges of the panel identified on the surface plots confirms what was expected, which is heat is being lost by convection and radiation from these surfaces. The cooler edges may also be attributed in part to the air conditioning system installed at the facility. If so it may be a factor as to why the problem is intermittent as the air conditioning system is not always on, it depends if the facility is hot.

The presses have several automatically actuated valves. If any of these valves have problems with their operation, such as a piece of loose debris is jamming it open, the control system will be unaware of this and assume it is functioning properly. If bowing of panels occur and the debris is subsequently washed away in the next cycle from the automatic operation of the valve, the bowing would seem to be a random event.

7.0 Conclusion

As has been shown from the analysis and testing for the Ayres Composite Panels/CEED project 'Identification of parameters which influence panel flatness and their control', many factors may influence the temperature of the panels when manufactured. It is the student's opinion that not one but several factors are the major parameters influencing panel flatness. When the combinations of these parameters are sufficiently unstable, the temperature profile and rate of temperature change occurring in a daylight may cause panels to bow.

Among the recommendations to be presented to the client are the following:

- Serpentines should be checked for throttling and cleaned where necessary.
- If skins are turning up at the ends they should be positioned such that the induced stresses and strains are opposing.
- The control system should be reviewed and modified where necessary.
- Corrosion prevention measures should be used to extend the life of the presses and to limit any corrosion build up in the platen serpentines and piping systems.
- De-mineralized water should be considered in the cooling system to prevent any scale forming in the serpentines and piping systems.

8.0 References

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9.0 Figures

Figure 1: Reproduced with kind the permission of Ayres Composite Panels.