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Investigating the Effect of Change in Resin Content on the Nature of the Laminate Sheet

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Abstract—*The following study looks at laminates in greater depth and attempts to investigate a factor in the manufacturing process that can cause a laminate to be bent and unusable. In this study I will be focusing on how the resin[1] content in the components of a laminate can affect the warping[2] of the laminate. The data in this study was obtained by conducting experiments at the Samrat Plywood Limited (Mica division) manufacturing plant in Nalagarh, Himachal Pradesh. Most of the information provided in the paper is primary data obtained from interacting with the technicians at the firm thus increasing credibility.*

Introduction

Laminates are layers of craft paper with a decorative layer bonded together and are applied on surfaces such as wood, plywood, fibre boards and so on to give them a finished and aesthetic look. Laminates are used everywhere in the furniture industry. Laminates suffer from warping or bending of mainly two forms that can prevent correct bonding of the laminate to the substrate due to formation of bubbles, resulting in delamination. During my summer vacation I worked at my father's company Samrat Plywood Limited – a renowned laminate manufacturer in India – and was intrigued by the minute technicalities of the manufacturing process. Hence, I conducted a small experiment to investigate determinants of the quality of laminates. The laminates created at the manufacturing plant are 1mm thick High-Pressure Laminates (HPLs) and hence the scope of my study is restricted to them. These HPLs are made using 6 layers of craft paper and 1 layer of decorative paper as can be seen in the figure below.

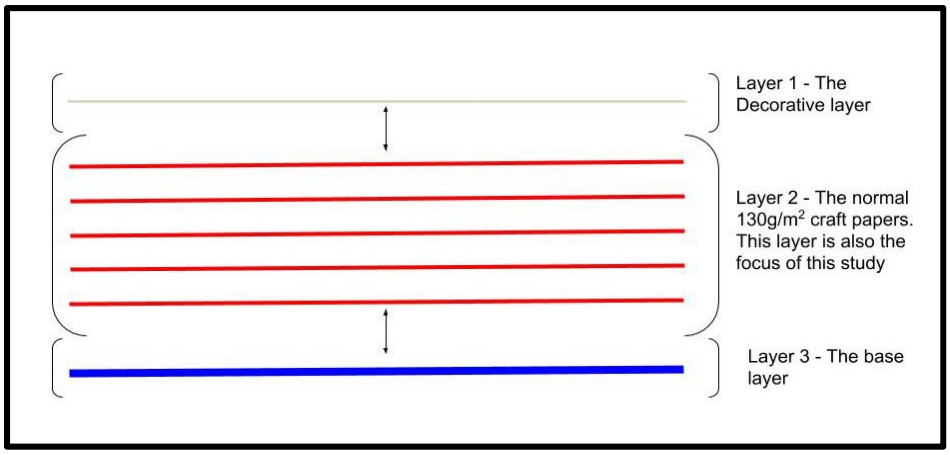


Figure 1.1: Composition of a sheet of HPL

The sheets are bonded together by a curing process under high temperature and pressure followed by cooling. The resin used in this process is Phenol Formaldehyde which is a thermosetting[3] resin commonly used in this industry. Phenol Formaldehyde is made by reacting phenol and formalin solution to create a polymer. Since phenol formaldehyde is a thermosetting resin, it requires a high temperature and pressure to work. This condition is provided by a laminate press.

[1] Resin is a Phenol Formaldehyde polymer also used as an adhesive
[2] Warping is the unwanted bending of a material
[3] A thermosetting resin is one that becomes irreversibly hard when cured

However, the reason that Phenol Formaldehyde is such an exceptional adhesive is because it binds with the lignin (a phenol-based compound found in trees) in the craft paper.

The RC (Resin Content) values and the VC (Volatile Content) values play a pivotal role in dictating the warping of laminates. VC and RC are discussed later in greater depth.

To get a better insight into the bending of laminates, we can classify them into two categories - Forward Bending (usable) and Reverse Bending (unusable).

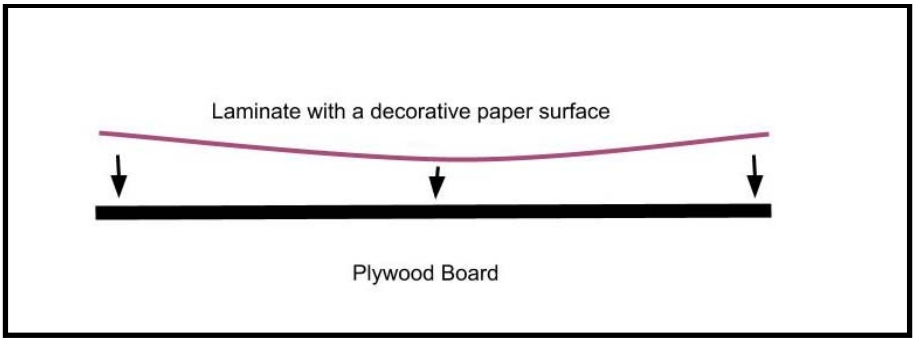


Figure 1.2: Forward (usable) bending in a laminate

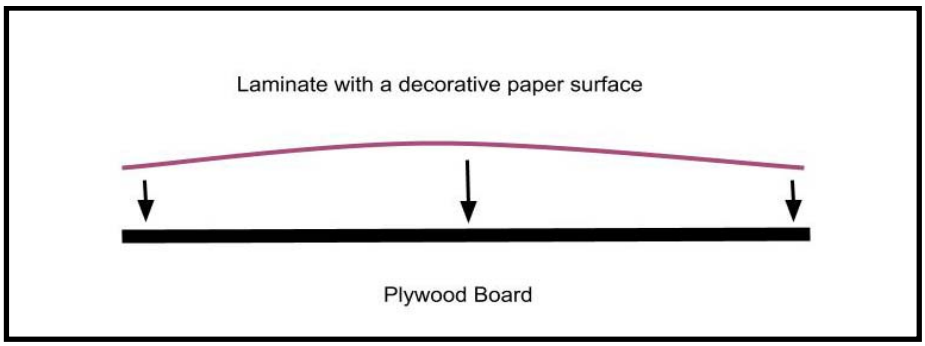


Figure 1.3: Reverse (unusable) bending in a laminate

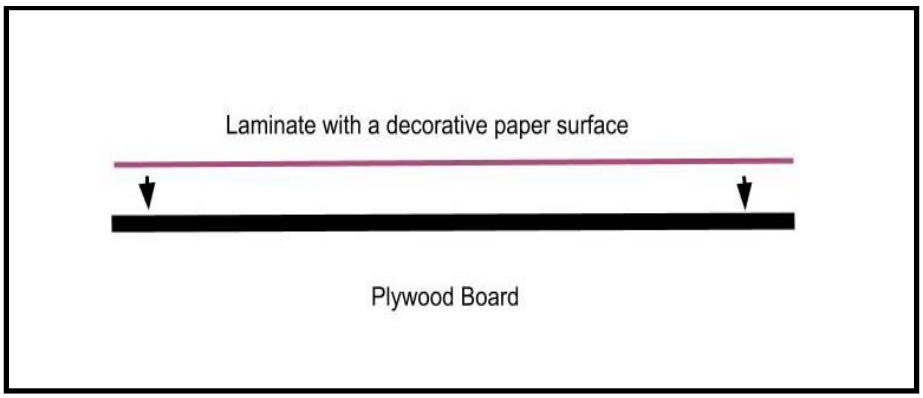


Figure 1.4: An ideal sheet of laminate

In the diagrams shows above, the colored line represents the laminate while the thick black line represents the plywood board[3] that the laminate is applied on. Figure 1.2 shows forward bending which forms a parabolic shape with its apex at the bottom and Figure 1.3 shows reverse bending that forms a parabolic shape with the apex at the top. Lastly, figure 1.4 shows the ideal laminate. In figure 1.3 we can see why reverse bending is considered harmful; the central protruding area does not allow the laminate to be applied to a flat surface and detaches from the surface, re-forming the arc.

This is due to the "memory" of the compressed fibres that causes the sheet to return to its original state. While forward bending is not necessarily good, since there is a tendency of the paper to rise from the edges, this tendency can be overcome by taping it at the ends, hence classifying the laminate as usable.

RC and VC values are extremely important in dictating the bending or properties of the laminate. Each layer of the laminate (the craft papers) is individually passed through a solution of Phenol Formaldehyde, absorbing the phenol formaldehyde in the process. The amount of phenol Formaldehyde absorbed by the craft paper refers to the Resin Content in the craft paper and is measured as a percentage increase in the mass of the craft papers. The RC value is controlled primarily by adjusting the distance between squeezing rolls (see diagram below) that the sheets pass through. A smaller distance between the squeezing rolls will cause the RC value to drop as a larger proportion of the resin is "squeezed" out of the craft paper. When the distance between the squeezing rolls is increased, the opposite takes place. Volatile Content on the other hand refers to the constituents or substances in the resin that evaporate during the curing process. This leads to a reduction in mass of the paper and the percentage by which the mass reduces is the VC value.

Research Question:

*"How does the **resin content** of the layers of a laminate sheet affect the bending of the laminate, assuming all other factors remain constant?"*

At Samrat Plywood Limited, I learnt that, although, in theory the VC value does not depend on the RC value, in practice there is a correlation. The VC value, according to the staff at Samrat Plywood Limited, is an extremely important factor in dictating laminate quality and hence so is the RC value, indirectly. Therefore, since the RC value was something that could be controlled, I decided to investigate the relation between the RC value and nature of bending. However, to re-confirm and establish a relation between the RC values and VC values I measured the VC values as well.

Objective

The primary objective of this study is to determine the relationship between the RC values and the corresponding quality of laminate produced. This is a valuable study to ensure more consistent laminate production at Samrat Plywood Limited. The secondary objective is to provide more concrete literature for the use of the company and also other laminate manufacturers.

Hypothesis

After conducting research and talking to the people in charge of the manufacturing process, the hypothesis was formed. At relatively low values of RC there will be forward bending; as the RC value is increased, the forward bending's magnitude will reduce until it eventually flattens out at the optimum point, beyond which there will be Reverse bending. The primary reason for this, I believe, is the negative correlation between the RC and VC values. The VC value in the case of Phenol Formaldehyde resin is extremely important as while there are several small volatile compounds in the resin, Formaldehyde itself is a Volatile Organic Compound (VOC) and hence a smaller VC value would lead to a greater concentration of Formaldehyde being present. Similarly, when the VC value is larger, it indicates a lower concentration of Formaldehyde. Formaldehyde concentration is extremely important in the binding of the papers as it is a key component of Phenol Formaldehyde. However, if the concentration of Formaldehyde is high (low VC value), it will lead to the paper binding very strongly and hence contracting when cured in the pressing machine. This contraction of the middle layers will lead to reverse bending in the laminate. Similarly, as the formaldehyde concentration decreases (high VC value) the paper will become "loose" and expand due to a relatively weaker adhesive. This will then cause the laminate to undergo forward bending. At a certain concentration of Formaldehyde, however, this bending is negligible and can be considered an ideal or flat sheet of laminate which is what is required.

I viewed the phenomenon of warping sheets in a manner similar to that seen in bi-metal strips, where one strips expansion due to heat causes bending in the second strip as well.

Independent Variable: The RC value of the craft paper that was measured by calculating the percentage increase in the mass of the paper. This was done by cutting a small section of the paper and testing it.

Dependent Variable: The degree of bending observed in the final laminate.

Controlled Variables:

- Consistency of craft paper ($130 g/m^2$), layers of craft paper (6), absorbance of craft paper
- Speed of going through the resin, the batch of glue through which all the samples were passed,
- The pressure and heat applied during the curing process,

- The top decorative layer of paper impregnated in Melamine Formaldehyde was identical in all batches,
- The bottom layer (plywood board) was also the same in all the batches. The top and bottom layers could be kept constant as they were produced separately.

Methodology

Since the study I wanted to conduct was impromptu and disruptive to the manufacturing process, I was granted very little freedom and was allowed one trial only. Additionally, the technicians handled most of the process of creating the laminate since it requires high precision and expertise while I was primarily involved in determining the procedure and noting and analyzing the data.

The determination of the distance between the squeezing rolls to vary resin content was done by referring to pre-existing data of the company.

1. I first decided the RC values that I was going to work with: 22%, 24%, 26%, 28%, 30%, 32%.
2. Next, the squeezing rolls were adjusted (using prior data) by the technicians to obtain an RC value within 0.25% of the desired value. The 0.25% variation was allowed since getting the exact value would require lots of fine tuning and hence a lot of time. 30 seconds after the distance between the squeezer rolls was determined, a small sample (0.1m x 0.1m) was cut out from one of the sheets and the RC value was measured. While measuring the RC value at this point, it was assumed that the sheet had an initial mass of $130g/m^2$. However, if the RC value was not within 0.25%, the squeezer rolls were adjusted a little until the correct value was obtained.
3. After the masses and RC values of the 6 correct samples had been noted, these samples were heated at 140˚C for 3 minutes in an oven. These conditions replicated the conditions occurring in the curing process and hence provided a reliable and measurable value of the VC. The loss in mass for each sample was noted and the VC was calculated as a percentage.
4. After the necessary measurements were made and the data was collected, the factory workers and I assembled 6 laminates. In each of the 6 laminates the middle layers varied while the top and basal layers were identical. In each laminate sample, the middle layer was composed of 5 craft paper of the same RC value. Hence, for 6 RC values, 6 laminates were created.
5. Each laminate was marked by me for later Identification.
6. Then, these laminates were sent underwent curing as per the normal production cycle (duration: 45 minutes, Temperature: 140˚C, Pressure: 7000Pa)
7. Once, the sheets had been pressed, they underwent normal production processes wherein the edges were trimmed to get the final size, the bottom layer was put in the abrasive sanding machine to shave off the excess and the bottom layer was made rough (to aid its bonding to a substrate)
8. Finally, once the laminates had been created, they were stored for one week and the observed for the nature of bending (flat, reverse bending or forward bending)

Raw Data Table:

Initial Mass of the craft paper: $130g/m^2$

Trial Number	mass of craft paper sample after impregnation / grams	Mass of craft paper sample after heating at 140 for 3 minutes/ grams
1	**1.588**	**1.497**
2	**1.609**	**1.514**
3	**1.635**	**1.537**
4	**1.665**	**1.564**
5	**1.693**	**1.588**
6	**1.717**	**1.609**

Sample Calculations:

For all sample calculations, Trial 1 has been used.

1. Finding the mass of the entire craft paper from the 10cm x 10cm sample:

$$\text{mass of Craft Paper} = \frac{\text{mass of 10cm} \times \text{10cm piece}}{\text{area of the sheet}}$$

$$= \frac{1.588 \text{ grams}}{0.01 \text{ m}^2}$$

$$= 158.8 \frac{\text{g}}{\text{m}^2}$$

2. Finding the percentage increase in mass (RC value):

$$\text{Percentage increase in mass} = \frac{\text{change in mass}}{\text{initial mass}} \times 100$$

$$= \frac{158.8 - 130}{130} \times 100$$

$$= 22.15\%$$

3. Calculating the VC value:

To be able to calculate the VC value, the 10cm x 10cm craft paper sample was heated first and the mass it mass was recorded.

$$\text{new mass of Craft Paper} = \frac{\text{mass of 10cm} \times \text{10cm piece}}{\text{area of the sheet}}$$

$$= \frac{1.479 \text{ grams}}{0.01 \text{ m}^2}$$

$$= 149.7 \frac{\text{g}}{\text{m}^2}$$

Next, the new mass (after heating) was expressed as a percentage of the old mass (after impregnation) and this was the VC value.

$$\text{Percentage decrease in mass} = \frac{\text{change in mass}}{\text{initial mass}} \times 100$$

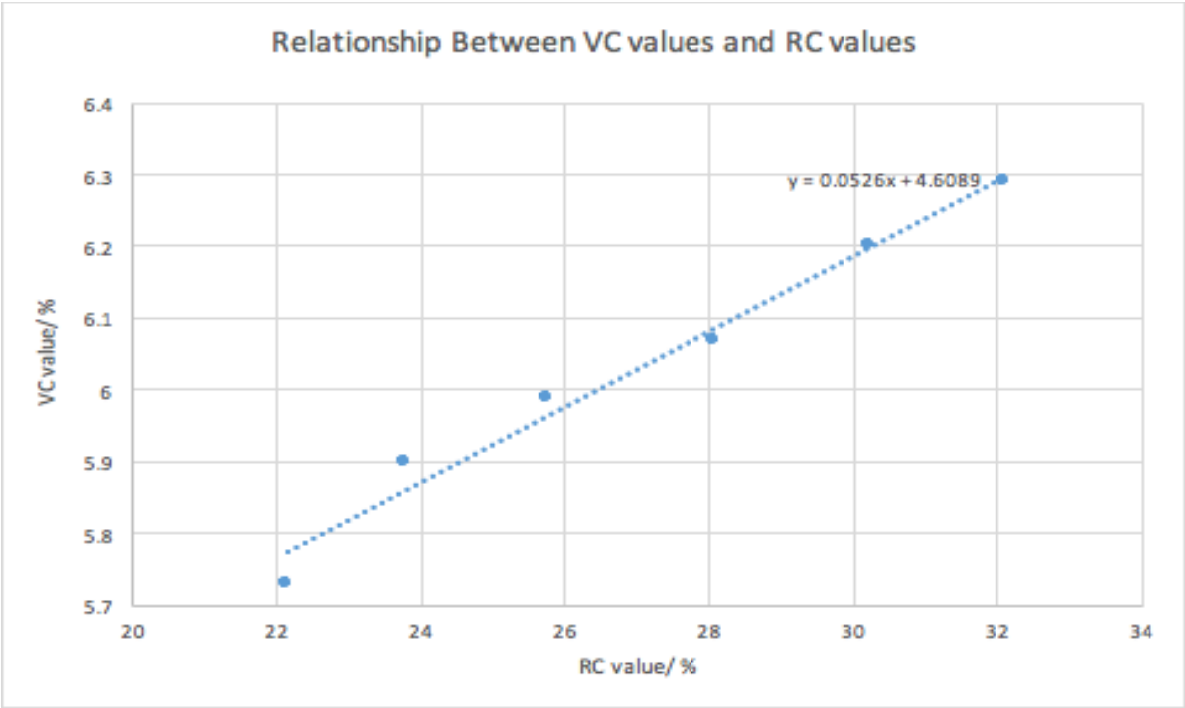
$$= \frac{158.8 - 149.7}{158.8} \times 100$$

$$= 5.73\%$$

Processed Data Table:

Trial No.	Mass of craft paper after impregnation/ g	Percentage Increase in mass (RC value) / %	Mass of craft paper sample after heating/ g	VC value /%	Nature of Bending
1	**158.8**	**22.15**	**149.7**	**5.73**	**Forward Bending**
2	**160.9**	**23.76**	**151.4**	**5.90**	**Forward Bending**
3	**163.5**	**25.76**	**153.7**	**5.99**	**Flat**
4	**166.5**	**28.08**	**156.4**	**6.07**	**Flat**
5	**169.3**	**30.23**	**158.8**	**6.20**	**Reverse Bending**
6	**171.7**	**32.08**	**160.9**	**6.29**	**Reverse Bending**

Graph showing the practical relationship between VC and RC values:



Conclusion

From the processed data table above, we can see that as the RC value increases, the VC value increases as well. We can also see that at a low RC (and VC) value the nature of bending in the laminate sheet is forward bending; at slightly higher RC (and VC) values the laminate sheet was flat and at any RC (and VC) value beyond this there was reverse bending. This agrees with my hypothesis. Additionally, from the Graph showing the practical relationship between VC and RC we can see that there is a positive correlation between the RC and VC values in a practical scenario. This correlation can prove to be extremely useful in improving laminate quality at the manufacturing plant since it provides qualitative backing. Moreover, there the uncertainty values for only the weighing scale were available to me at the Samrat Plywood Limited manufacturing plant and hence I decided to ignore uncertainties for the simplicity. However, the random error may have been slightly higher since I was not allowed to take multiple trials. Lastly, I wanted to derive the extent of bending in the laminates mathematical using geo-gebra; however, due to restrictions imposed by the factory I was only allowed to observe the laminates and note their nature. It is also worth mentioning that care immense care should be taken when working with Phenol Formaldehyde, since the VOC Formaldehyde is carcinogenic at high concentrations.

Evaluation

I believe that the experiment, although conducted once, yielded worthy results and quantified what I had hypothesised based on what I learnt from the factory technicians. The trend that I have found can be used by Samrat Plywood Limited in their quality control measures as I have proved that with a change in RC value, the quality of laminate can also change. However, it is worth mentioning that in a manufacturing plant such Samrat Plywood Limited's several other factors can also affect the quality of the laminate such as the viscosity of the Phenol Formaldehyde, the impregnation conditions etc. Since the Hypothesis I had formulated proved to be true, I decided to further explore the reasons that could have caused the bending to change in this manner and hence I decided to speak to the owner of another Laminate manufacturing company - Euro Decor Private Limited. While discussing my results and research, we formulated another possible reason why the nature of bending can be dictated by the amount absorbed by the craft paper. It is as follows - when the craft paper contains a high amount of Phenol Formaldehyde resin, the curing process causes the middle layers to become much harder than the top and bottom layers. This hardness in the middle layers can then cause Reverse bending. The opposite holds (forward bending) true if the resin present in the middle layers is very less. However, one factor cannot be isolated and the contractionary/ expansionary effect of resin content combined with the hardness factor may determine the nature of bending. This again proves to be helpful for the company since further depth in the causation of bending can help them find cheaper and quicker countermeasures to fix batches if need be.

Extension

This research paper only manages to scratch the surface of the chemistry and physics involved in the manufacturing process of laminates. However, there exits ample scope in the improvisation of glues - Phenol Formaldehyde, improvisation of machinery and much more. I would also recommend further trials of the proposed data and hypothesis since a major limitation for me was lack of trials and images.

Acknowledgements

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