Improving Abrasion Resistance of Laminate Floor with Additional Curing Prior to Final Coating – An Experiment and SAS Program

Mutha Raju Nandipati [a*#], Dr. Suman KNS [b]
[a] North Carolina State University Graduate, M.Ed. (Technology education)
[b] Department of Mechanical Engineering, Andhra University, A.P., India.
[#] Engineering Manager in Multi-national wood manufacturing industry in North America

Abstract:- In the present work, an experiment was designed and conducted with one treatment factor and one blocking factor for Randomized Complete Block Design (RCBD) and analyzed to investigate the effect of three different curing temperatures with four different batches of resin for abrasion resistance of the laminated board surface. Curing temperature as treatment factor and batch of the raw material which was a resin as blocking factor were considered for this experiment. Abrasion resistances were measured with four levels of replication with randomly selected samples. Data analysis was done using SAS software for ANOVA test. Results of abrasion resistance values for 12 wood species used for flooring were analyzed and found that the curing temperature influences the abrasion resistance. Also found that the resin used in the process influences the abrasion resistance. By blocking the resin batches in the experiment, temperature influence on the abrasion resistance was analyzed.

***Keywords**:- Laminated Wood Flooring; Taber Abrader; RCBD; ANOVA; SAS.*

I. INTRODUCTION

The demand for wood flooring materials is reaching record levels due to growth in residential and commercial building industry. Wood flooring is gaining momentum due to its natural, hypoallergenic, resistance to wear, and aesthetic qualities when compared to other types of floor finishing material such as vinyl, concrete, or ceramic tile etc. The global market for wood flooring is expected to rise nearly 7% per year, according to Technavio [1]. The flooring industry is starved for revolutionary product innovation. Internal cost control, meeting regulatory compliances, and reduce the inputs necessary to produce each finished unit [2]. Laminated flooring manufactured from high density fiberboard (HDF) is less expensive than other types of engineered and solid wood flooring [3]. Utility surfaces such as kitchen tops, staircases, and floorings are subjected to different loadings (mainly frictional) causing wear. Visual or surface defects of wooden floors such as staining or color change, scratches, abrasions, and stains will happen due to inadequate maintenance, and wear of the wood material [4]. Sufficient research is conducted to investigate the surface properties of the solid wood (SW) flooring materials with different coatings and on substrate improvement with different compositions such as magnesium oxide to improve density, bending characteristics, internal bond strength, and thickness swelling [5]. Very limited research is conducted on laminated wood (LW) flooring materials for their abrasion resistances compared to solid and engineered wood (EW) materials. Equipment manufacturers such as Nantong Haushunda, VITS-Germany, and Tocchio are designing their machines with ambient air cooling before the application of melamine coating. No further research has been conducted on how important the cooling (curing) temperature to improve the melamine coating was done. In this present experiment, a heat exchanger with chilled water supply was introduced to optimize the curing temperature so that the abrasion resistance of the surface can be improved.

With latest trend of using laminated particle boards (panels) in the construction of cabinets, furniture, tabletops, and work benches at educational establishments, researchers are focusing on optimizing the manufacturing process and product quality. These laminated boards are manufactured with raw particle boards pressed together with decorative paper on top and bottom with the application of heat and pressure. Surface properties such as abrasion and wear resistances which are highly important for the furniture are coming from the decorative paper used as top layer of the panel. The decorative paper is made from impregnation process where raw paper is saturated with urea and melamine formaldehyde resins along with other additives at two different stages. This process can be understood with the following figure 1:

ISSN No:-2456-2165

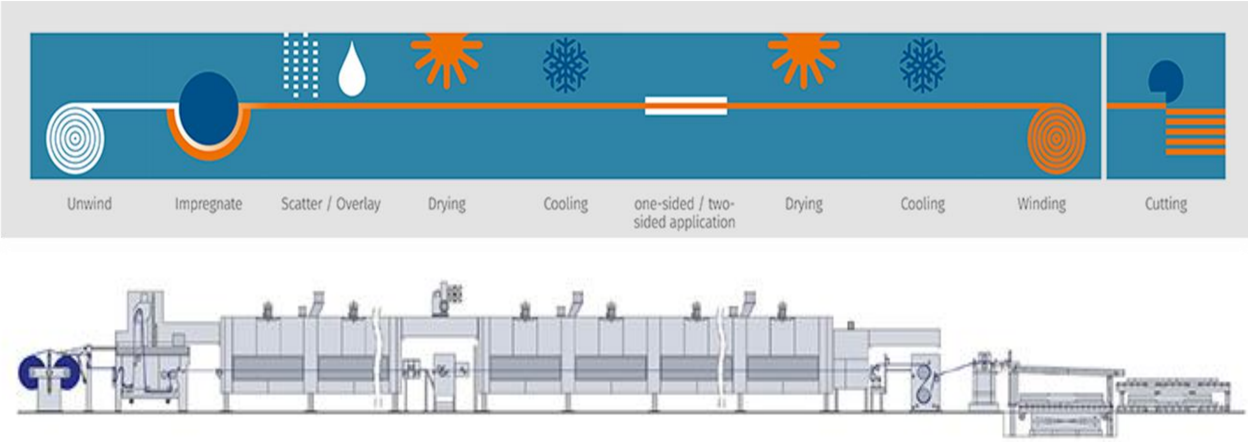


Fig.1: Impregnation line for decorative paper used in furniture boards, courtesy: VITS, Germany.

Raw paper in a roll form will be fed at the front end of the machine, chemical with major part as resin is applied at two different stages. At the first stage, urea formaldehyde resin is used and in subsequent stage melamine formaldehyde resins been used. The saturation of urea resin with decorative paper makes a difference in abrasion resistance. Unsaturated urea resin at the surface of the paper causes for lesser abrasion resin. To increase the saturation, process is improved through more cooling after the drying process before the application of second stage melamine resin coating. An experiment is conducted with three different cooling temperatures. During the process, also felt that the resin used with different batches may affect the abrasion resistance. It was our interest to investigate the effects of three different levels of cooling temperature on abrasion resistances considering batches of resin as blocks. Laminated particleboard used for furniture is having the structure shown in figure 1, top and bottom layers are decorative impregnated papers and middle is the raw particle board.

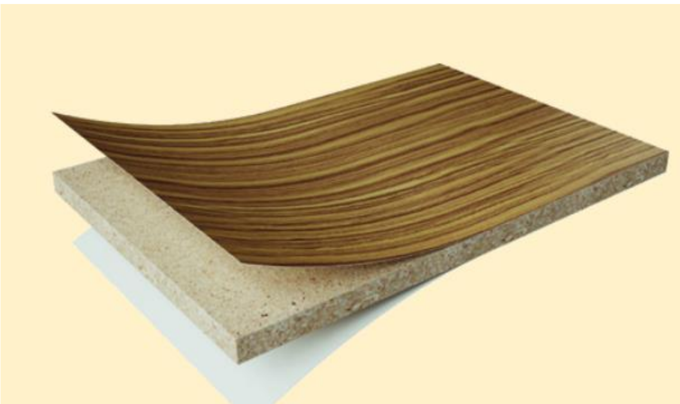


Fig 2. Structure of laminated particle board (courtesy: Sonitex Laminates)

Laboratory testing of wood samples to measure the abrasive resistance will use the equipment called Tabor Abrader, the most used laboratory equipment in the industry. The abrader consists of two rollers covered with sandpaper and mounted on a balanced axle. The axle is loaded with a given vertical force, and the sample is rotated under the rollers to visualize the material loss per standard revolutions [6].

Analysis of variance (ANOVA) was used to analyze the data to test the hypothesis. Tukey's Multiple Comparison Test was used to compare the groups. SAS software was used for all the analysis part.

In a nutshell, the background of this experiment was to investigate the influence of curing temperature on the surface property of abrasion resistance. It was felt that different resin batches used as raw material may also influence the abrasion resistance and skew the comparisons. Hence resin batch as blocking factor was used while conducting this RCBD.

II. METHODS

A. *Experimental Design*

This was a randomized complete block design (RCBD). Each of the three samples in every resin batch are collected randomly, and batches are subjected to different cooling temperatures randomly by varying the temperatures at chilling plant. Samples were collected with all other operating parameters same throughout the experiment. Each sample was tested for its abrasion resistance by using the same instrument with all conditions same. Cooling temperature was an independent variable and abrasion resistance waas a dependent variable. The main idea of conducting this experiment was to test the influence of curing temperature on surface quality of abrasion resistance. During the process found that the raw material used was not from the same batch as this was coming from an external source and hence batches of resin was considered as a blocking factor to conduct this RCBD experiment.

B. *Sample Preparation*

Four samples each for each temperature for four different resin batches are selected randomly by a quality lab technician to test them for abrasion resistance values.

C. *Abrasion Test:*

Taber abrader [7] was the instrument used for this measurement as shown in figure 4. The sample (4-inch x 4-inch) square clamped to the rotating table spins at 60

ISSN No:-2456-2165

revolutions per minute. The sample was pressed by the abrasive wheels and additional weights. Abrasive friction due to rotation of the sample and loaded abrasive wheels caused for deterioration of the surface. Number cycles needed to visualize the surface wear was the measure of the abrasion resistance. The test was conducted by following the operating procedures laid down by Taber industries referring to EN13696 standard.

Figure 4. Taber Abrader lab equipment

D. Statistical Analysis

Abrasion resistance values in revolutions for all twelve samples were collected and tabulated as shown in table 1. As the curing temperature decreases the abrasion resistance values were went down. Mean abrasion resistance value at coolest temperature of 137 deg F was found as 451 cycles whereas for 143 and 150 deg F the abrasion resistance values came down to an average of 435 and 422 cycles. Hypothesis for this experiment was 'curing temperature affects the mean abrasion resistance of the surface'.

Curing Temperature (deg F)	**Batch number of the Resin (Block)**			
	1	**2**	**3**	**4**
137	450	455	436	464
143	434	446	421	442
150	422	439	399	428

Table 1. Abrasion resistance values in revolutions

It was suspected that there may be significant batch-to-batch variation because of the resin deliveries are from external source. We decided to investigate the effect of three different curing temperatures on abrasion resistances using a randomized complete block design [8] considering batches of resin as blocks. ANOVA was conducted by using the SAS software. Model adequacy was checked before conducting the ANOVA with the use of same SAS.

Statistical analysis was conducted by following six steps:

Step 1: Defined the null hypothesis H_0: all mean values of abrasive resistances are not significantly different and alternate hypothesis H_1: at least one mean was different from others.

Step 2: Use level of significance of 0.05, $\alpha = 0.05$.

Step 3: Finding test statistic F. SAS software was used to find the F statistic from ANOVA and Tukey's model. SAS code and results are included in Appendix 1.

Step 4: Finding the *p* (probability) value.

Step 5: Deciding on hypothesis based on *P* value in comparison with level of significance.

Step 6: Conclusions on this experiment which was explained in detail in the next session.

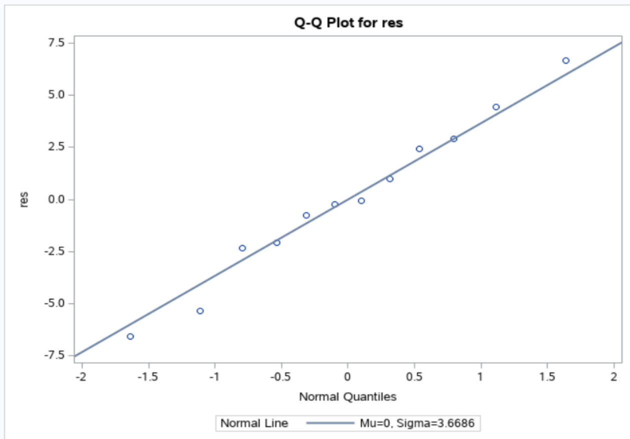
III. RESULTS AND DISCUSSIONS

A. Model adequacy for RCBD:

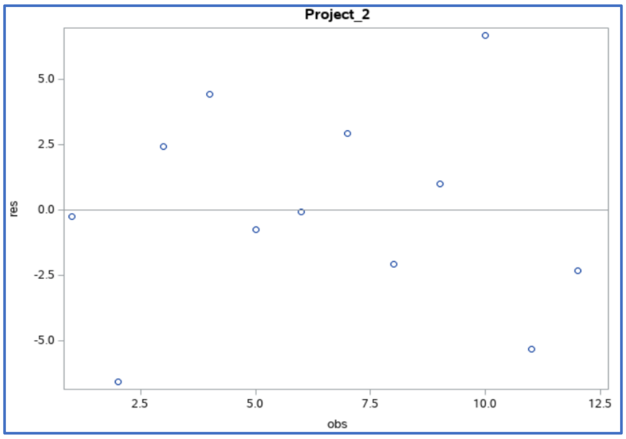
SAS software was used with following results:

- From Shapiro-Wilk test, as the p value (0.9957) was greater than level of significance of 0.05, and the Q-Q plot for residuals was showing a straight upward line, we can conclude that the model was adequate from normality point of view.

Tests for Normality				
Test	Statistic		p Value	
Shapiro-Wilk	W	0.984458	Pr < W	0.9957
Kolmogorov-Smirnov	D	0.10461	Pr > D	>0.1500
Cramer-von Mises	W-Sq	0.019258	Pr > W-Sq	>0.2500
Anderson-Darling	A-Sq	0.136685	Pr > A-Sq	>0.2500



- As the plot below shows no clear pattern in the plot, we can conclude that the observations are random and independent.



As the model was found adequate, hypothesis was tested as below:
Step 1: Null hypothesis H_0: No effect of curing temperature on abrasion resistance. Alternate hypothesis H_1: There was an effect of curing temperature on abrasion resistance.
Step 2: Assume level of significance as 0.05.
Step 3: Test statistic: $F_{2,6} = 31.82$
Step 4: p-value for the test statistic, 0.0006
Step 5: As the p value was less than 0.05, reject null hypothesis
Step 6: We can conclude that there was an effect of curing temperature on abrasion resistance.

Dependent Variable: resistance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	3181.166667	636.233333	23.64	0.0007
Error	6	161.500000	26.916667		
Corrected Total	11	3342.666667			

R-Square	Coeff Var	Root MSE	resistance Mean
0.951685	1.189028	5.188127	436.3333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
temperature	2	1713.166667	856.583333	31.82	0.0006
batch	3	1468.000000	489.333333	18.18	0.0020

Source	DF	Type III SS	Mean Square	F Value	Pr > F
temperature	2	1713.166667	856.583333	31.82	0.0006
batch	3	1468.000000	489.333333	18.18	0.0020

B. Blocking Factor Affect:

From the results shown below, with test statistic F 1,6 = 1.99 and p value of 0.2175 which was greater than 0.05, we can conclude that there was no interaction between temperature and batch of resin.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
temperature	2	61.38527052	30.69263526	1.33	0.3446
batch	3	61.48014529	20.49338176	0.89	0.5081
q	1	45.95778343	45.95778343	1.99	0.2175

From the results shown below, the test statistic $F_{3,6} = 18.18$, and p value is less than 0.05, we can conclude that there was an interaction between resin batch and abrasion resistance from blocking point of view.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
temperature	2	1713.166667	856.583333	31.82	0.0006
batch	3	1468.000000	489.333333	18.18	0.0020

IV. CONCLUSIONS

This study was conducted to test the curing temperature effect on abrasion resistance as a surface quality (laminated particle board). Results from ANOVA test using SAS software revealed the following facts:

a) Model adequacy was checked uniformly distributed data points from residual plots, straight line from normality plot (Q-Q plot), from Shapiro-Wilk test, as the p value (0.9957) was greater than level of significance of 0.05. Found model was adequate with no concerns.
b) Abrasion resistance values were dependent on curing temperatures.
c) Found there was no interaction between curing temperature and resin batch. However, curing temperatures and resin batches were independently affected the abrasion resistance values. With analysis conducted with resin batch as blocking factor, the temperature effect on abrasion resistance was concluded easily as 'with temperatures coming down (cooler), found the abrasion resistance values high'.

REFERENCES

[1]. Wood flooring manufacturing - quarterly update 1/18/2021. (2021). (). Fort Mill, South Carolina: Mergent. Retrieved from ProQuest Central Retrieved from https://login.proxy181.nclive.org/login?url=https://www.proquest.com/reports/wood-flooring-manufacturing-quarterly-update-1-18/docview/2478768606/se-2?accountid=13153.

[2]. Bischoff, M. (2020). PARTNERING FOR SUCCESS starnet members and wholesale flooring distribution. *Floor Trends, 22*(7), 40-44. Retrieved from https://login.proxy181.nclive.org/login?url=https://www.proquest.com/trade-journals/partnering-success-starnet-members-wholesale/docview/2424657113/se-2?accountid=13153

[3]. Aslanova, F., Elkiran, G., Hiziroglu, S., & Ilseven, S. (2020). Selected properties of overlaid magnesium based composite panels for flooring. *Applied Sciences, 10*(15), 5028. doi:http://dx.doi.org/10.3390/app10155028

[4]. How long can a wood flooring system last? (2021). *Buildings, 11*(1), 23. doi:http://dx.doi.org/10.3390/buildings11010023

[5]. Dilik, T.; Hiziroglu, S. Some properties of linoleum and wood laminated flooring Panels with magnesium substrate. Bioresources **2015**, 10, 1667–1674. [CrossRef]

[6]. Joseph V. Koleske, Paint and coating testing manual, fourteenth edition of the Gardner-Sward handbook, 1995.

[7]. Righeira Carnegie, M., Sherine, A., Sivagami, D., & Sakthivel, S. (2016). Anti-reflection coatings with enhanced abrasion and scratch resistance properties. *Journal of Sol-Gel Science and Technology, 78*(1), 176–186. https://doi.org/10.1007/s10971-015-3924-9

[8]. Douglas C. Montgomery, Design and Analysis of Experiments, 8th edition, John Wiley & sons, inc., 2012.

[9]. Impregnating machine, https://www.vits.com/en/plantengineering/vits-plants/

[10]. SAS programming, https://welcome.oda.sas.com/home.