Identification of process parameters contributing major effects in plywood manufacturing through DOE, an effective TQM Tool: Testing Modulus of Rapture of finished plywood as response

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Abstract: *Plywood industry is a conventional industry using mostly conventional process and the output that is generated i.e. plywood thus obtained become subjected to several failures since quality thus generated out of conventional manufacturing process parameters do not posses necessary quality parameters. Sine plywood is subjected to mechanical load, even sometimes sustained pulsating load etc. it becomes subjected to different types of failure. Out of different types of failure to which plywood is subjected, rapture failure is a very common one.*

Suitable quality management is necessary to eliminate such type of failure and TQM is an effective means towards this and TQM practices provide an effective contribution towards management of process parameters with necessary quality enhancement effect towards elimination of different types of failures like tensile failure, compressing failure, availability of suitable elastic limit, etc through DOE and above every aspect of quality management TQM creates situation in quality management having contribution over major effects in plywood manufacturing process through DOE: testing modules of rapture of finished plywood, very critical criteria, as response.

Key words: process parameters, quality circle, rapture, failures, DOE (design of experiment)

1.0 Introduction

Although Wood based engineered products are being manufactured by so many manufacturers in India and throughout the world but there was not consistency in output parameters. Though there are set values of input factors by different standard and specifications by the apex government bodies of different countries less studies has been done on which parameter and which interactions of factors are most significant. We know that Plywood is the substitute of timber wood mostly used for domestic use, manufacturing furniture and construction purposes. All plywood bind resin and wood fiber sheets to form a composite material. Plywood is tested for different mechanical properties such as, glue strength, tensile strength, modulus of rapture, modulus of elasticity, moisture content, heat resistance, biological resistance, finishing etc. to specify its quality. Most plywood when manufactured have their plies or layers of veneers arranged at right angles to each other. This arrangement gives the plywood strength. The layers of veneers such arranged, when hot pressed with different urea formaldehyde resin (UF Resin) or phenol formaldehyde resin (PF Resin) it gives many benefits such as :

a. Reduction of tendency of wood to split when nailed at the edge

b. Reduction of expansion and shrinkage of the plywood
c. Improvement in the dimensional stability
d. Consistent strength of the panel
e. Increase in Modulus of Rapture
f. Increase in Modulus of Elasticity
g. Low moisture absorbing capacity

Plywood is tested for different mechanical properties such as, glue strength, tensile strength, modulus of rapture, modulus of elasticity, moisture content, heat resistance, biological resistance, finishing etc. to specify its quality. The engineered wood is one of the reliable materials. It has been successfully used in variety of applications such as construction material, furniture, packaging, etc. Normally they are produced from wood, adhesive and fibre reinforcement that are bonded together by pressure and heat. Thus the properties of the product are depended on raw materials, wood, adhesive and fibre reinforcement, and processing conditions. The mechanical properties and durability are the prime interests for most of the applications. Plywood for general purposes as per Indian Standard IS-303: 1989 is one of the most common engineered woods. There have been a lot of publications reported on the improvement of mechanical and property and durability of the various form of wood. The veneers used in manufacturing plywood or any mean of wood sheets are important not only their strength but the abundant and diversifying and modification for value addition are greatly interests. Glues that play the important role for consolidating the wood constituent together have been also investigated and published

In the present investigation four parameters namely temperature, Pressure, press time and glue consumption rate have been considered as control factor and controlled during manufacture of samples. Modulus of Rapture (MoR) have been taken as response. Each factor has three levels. Normally the plywood are manufactured in size 8 ft X 4 ft having different thickness from 4 mm upto 19 mm in standard hot press with 10 to 12 daylight provision. But for the purpose of the present investigation the estimator has made the samples in a “Sample Hot Press” which has a maximum capacity of one square foot size. The advantage of this sample hot press is that it controls all the control parameters with 96 % accuracy (Source: Periodical Calibration Data). The reliability of the control parameter of a Sample Hot Press is high. There are number of wood bonding variables. Each of these variables or factors is significant for some end use characteristics. Controlling of these factors is necessary for manufacturing quality wood based product. Norm Kutscha has defined some of these variables. These are Viscosity of Resin, Cure Rate of Resin,

Filler used in Resin, pH of Resin, Species and density of wood, Moisture content of veneer, Plane of Cut: Radial, Tangential, Transverse, Mix, Porosity, pH of Wood, Glue Consumption, Glue Distribution, Relative Humidity, Press temperature, Pressure, Press Time etc.

After literature survey the estimator choose four factors for the investigation as they are significant in many areas. Moreover these can be controlled by the control system of above machine. In this report the processing parameters used to manufacture the plywood used for general purposes as factors and MoR as response will be discussed by mean of statistical Design of Experiment (DoE) and actual experiment practice respectively. ANOVA is the statistical treatment most commonly applied to the results of the experiments to determine the percentage contribution of each parameter against a stated level of confidence (Julie *et al*., 2007) Taguchi suggests (Roy, 1990) two different routes for carrying out the complete analysis. In the standard approach, the results of a single run or the average of repetitive runs are processed through the main effect and ANOVA (raw data analysis). Taguchi strongly recommends the second approach for multiple runs to use the Signal-to-Noise (S/N) ratio for the same steps in the analysis.

2.0 Objective of the Study

In the present investigation four parameters namely temperature, Pressure, press time and glue consumption rate have been considered as control factor and controlled during manufacture of samples. Modulus of Rapture (MoR) have been taken as response. Each factor has three levels. Normally the plywood are manufactured in size 8 ft X 4 ft having different thickness from 4 mm up to 19 mm in standard hot press with 10 to 12 daylight provision. But for the purpose of the present investigation the estimator has made the samples in a “Sample Hot Press” which has a maximum capacity of one square foot size. The objective of the study is to investigate:

a. Identification of process parameters contributing major effects in the response in plywood manufacturing.
b. Ranking, determination and thus selection of combination of levels of each identified process parameters through design of experiment (DOE)
c. Optimization of levels of the identified parameters through design of experiment (DOE)

3.0 Literature Review

Chinese and Egyptians are pioneers in shaving wood and gluing it together to get the special effects with veneered surfaces. Refering to the history of Plywood, we find that the English and French made a considerable progress in the general principle of plywood specially during 17^{th} and 18^{th} centuries. Neverthless, the Czarist Russia is also acknowledged for its valuable contribution in making a form of plywood prior to the 20^{th} century.

Plywood is made of sheets of plies or veneers arranged in ninety degree alternatively and bonded with urea formaldehyde resin or phenol formaldehyde resin. Plywood manufacturers generally go by odd number of layers, in which each layer may consist of one or more plies. Accordingly plywood can be described by the number of layers where the structure must be symmetric about the middle layer for balancing. Plywood maybe of 3 ply, 5 ply, 7 ply or 9 ply. In case of non-conventional 4 ply arrangement, the processing is accomplished using four plies of core veneer sheets where two layers are kept in the middle and two layers are kept symmetrically on the opposite sides of the middle veneer in ninety degree angle. As one of the most important forest products industries in India, the manufacturer of plywood helps in substituting timber for domestic use, manufacturing furniture and construction purposes. Researchers have made several studies on the identification and optimization of process parameters contributing major effects in manufacturing wood based engineered products such as plywood, block board, marine plywood, shuttering plywood, flash door, heat resistant plywood etc.

According to J. E. Marian (Marian, 1995), there are many factors responsible for the quality of the end product during manufacturing. He has listed twenty one such variable factors. These twenty one factors have been further grouped together and classified into three major classes as follows:

1. Wood Properties
2. Glue Properties
3. Gluing and Hot Press Operation Properties

The impact of all these factors are not uniform as some of these factors are more important than the other.

Design of Experiment (DoE) is defined as an experimental or analytical method which is commonly used by the researchers to statistically signify and establish the relationship between input parameters to output responses by following a systematic way of planning of experiments collecting and analyzing data for execution. It has wide applications especially in the field of science and engineering for the purpose of process optimization, process management and validation tests. Experimental design was first introduced in 1920s by R. A. Fischer. During research in improving the yield of agricultural crops (Alagumurthi *et al*., 2006)., he developed the basic principles of factorial design and the associated data analysis, which is known as ANOVA. In an experiment, the researchers deliberately change one or more process variables (or factors) in order to observe the effect the changes have on one or more response variables. The (statistical) design of experiments (DOE) is an efficient procedure for planning experiments so that the data obtained can be analyzed to yield valid and objective conclusions (Wang *et al*., 2007). In modern engineering this method is used in all major engineering and other process industries. The objective of the Taguchi method is

to determine the optimum settings of input parameters, neglecting the variation caused by uncontrollable factors or noise factors (Sivarao *et al.*, 2010). Optimization of multiple performance characteristics appear to be much more complicated than that of a single performance (Lin and Ho, 2003; Fung, 2003; Tarng *et al*., 2002; Lin *et al*., 2004; Huang and Liao, 2003). On the contrary, the Taguchi design is considered to be more effective than fractional factorial design as it emphasizes on the balanced (orthogonal) experimental combinations. Taguchi technique helps industries greatly to reduce product development cycle time for both design and production which in turn reduces costs and increases profit (Julie *et al*., 2007). Taguchi advocated a three-step approach for engineering optimization of a process or product. These three steps are to be carried out as follows:

1. System design
2. Parameter design
3. Tolerance design

The purpose behind parameter design (Ross, 1988) is to optimize the setting of the process parameter values for improving performance characteristics while identifying the product parameter values under the optimal process parameter values. The steps that are involved in the Taguchi parameter design are (Julie *et al.*, 2007):

1. Selecting the proper Orthogonal Array (OA) according to the number of controllable factors (Parameters)
2. Running experiments based on the OA

3. Analyzing data
4. Identification of Optimum Condition
5. Conducting confirmation runs with the optimal levels of all the parameters

The general trend of influence of each parameter is reflected in the main effect. Based on the knowledge of the condition of individual parameter the researcher is to decide the nature of the control to be exercised on a manufacturing process. From the literatures, it is observed that only few works have been reported on the study of wood-composite process parameters for FRP-veneer composite manufacturing and almost no work has been done on plywood manufacturing using DOE. Therefore the aim of the present study is to investigate the effect of process parameters in the response output of plywood for general purposes as per IS 303-1989. The experiment was conducted and analysis of data has been done using a statistical technique called Design of experiments (DOE). In this study ANOVA helped to identify the effect of each factor versus the objective function.

4.0 Research Methodology

4.1 Identification of Variables

Out of twenty one processes input parameters four input variables have been selected to be controlled during the present experiment. These are temperature, pressure, press time and glue consumption. Each variable has three levels. These are tabulated in Table 2

Sl. No.	Factors	Level 1	Level 2	Level 3
1	Temperature	140 °C	145 °C	150 °C
2	Pressure	14 Kgf/cm²	15 Kgf/cm²	16 Kgf/cm²
3	Press Time	20 Minutes	21 Minutes	22 Minutes
4	Glue Consumption	180 gm / ft. ²	210 gm/ft. ²	240 gm/ft. ²

Table 1: Factors and their Level for the present Investigation

Based on the published papers by the earlier researchers, it was found that temperature, pressure, time and glue amount during hot pressing are more important factors than other factors. Orthogonal Array L9 has been chosen to conduct the experiment. Accordingly nine samples are to be prepared. These nine samples will be made under different level of process control parameter as per L9. Table 2 has been give below:

Run	Factor A	Factor B	Factor C	Factor D
1	Level 2 of A	Level 2 of B	Level 3 of C	Level 1 of D
2	Level 3 of A	Level 2 of B	Level 1 of C	Level 3 of D
3	Level 2 of A	Level 1 of B	Level 2 of C	Level 3 of D
4	Level 1 of A	Level 3 of B	Level 3 of C	Level 3 of D
5	Level 1 of A	Level 2 of B	Level 2 of C	Level 2 of D
6	Level 3 of A	Level 3 of B	Level 2 of C	Level 1 of D
7	Level 1 of A	Level 1 of B	Level 1 of C	Level 1 of D
8	Level 3 of A	Level 1 of B	Level 3 of C	Level 2 of D

9	Level 2 of A	Level 3 of B	Level 1 of C	Level 2 of D

Table 2: Orthogonal Array L9

4.2 Preparation of Sample

Three basic raw materials will be required to prepare the samples. These are veneers, glue and fillers. The specification of the samples as per IS 303:1989 is Phenol Formaldehyde Boiling Water Resistant (BWR) Grade Plywood.. The thickness shall be 19 millimeter. The construction specification of the veneer assembly is as follows:

6 lines Glue Core	X	1.8 mm thick (Each)
4 lines Panel Core	X	1.8 mm thick (Each)
1 line Panel Core	X	2.5 mm thick (Each)
2 lines Face Veneer	X	0.45 mm thick (Each)

4.3 Test of Samples for Response Values

Once all the samples are manufactured they shall be marked with suitable marking. In this case they have been marked 1, 2,….. upto 9. These samples have been kept for some considerable period of two to two and half hours for normal air curing. Then test specimen were prepared for all the samples and carefully marked the same identification marks in each of these test specimen. The samples were then tested for Modulus of Rapture in Universal Testing machine (Capacity 2.5 Ton) and the results were recorded.

5.0 Data Analysis

The response values for each sample were fed in the Minitab software and were allowed to run. The significance of the model and the significant variable which contributes most were obtained from the result.The tests have been carried out in Essjay Technomeasure Pvt. Ltd. made 2.5 ton digital universal testing machine. Nine samples have been made and tested for Modulus of Rapture and the same has been tabulated in Table 3. Orthogonal Array L9 has been chosen for conducting the experiment. Accordingly factors and its levels have been selected for each run.

Run	Temperature	Pressure	Time	Glue	Response
1	Level 2 of A	Level 2 of B	Level 3 of C	Level 1 of D	40
2	Level 3 of A	Level 2 of B	Level 1 of C	Level 3 of D	50
3	Level 2 of A	Level 1 of B	Level 2 of C	Level 3 of D	39
4	Level 1 of A	Level 3 of B	Level 3 of C	Level 3 of D	47
5	Level 1 of A	Level 2 of B	Level 2 of C	Level 2 of D	43
6	Level 3 of A	Level 3 of B	Level 2 of C	Level 1 of D	52
7	Level 1 of A	Level 1 of B	Level 1 of C	Level 1 of D	48
8	Level 3 of A	Level 1 of B	Level 3 of C	Level 2 of D	44
9	Level 2 of A	Level 3 of B	Level 1 of C	Level 2 of D	39

Table 3: Level of Factors and corresponding Response Values

The software Minitab has been used for analysis of data. The response data for all the nine samples have been fed in the software and the results have been analysed, which has been given in Table 5

ANOVA for selected factorial model						
	Sum of		Mean	F	p-value	

Source	Squares	df	Square	Value	Prob> F	
Model	186.00	6	31.00	31.00	0.0316	significant
A-A	*172.67*	*2*	*86.33*	*86.33*	*0.0115*	
B-B	*2.67*	*2*	*1.33*	*1.33*	*0.4286*	
D-D	*10.67*	*2*	*5.33*	*5.33*	*0.1579*	
Residual	2.00	2	1.00			
Cor Total	188.00	8				

Table 4: Analysis of variance table [Classical sum of squares - Type II]

The Model F-value of 31.00 implies the model is significant. There is only a 3.16% chance that an F-value this large could occur due to noise. Values of "Prob> F" less than 0.0500 indicate model terms are significant. In this case Temperature is a significant model term. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

According to the fit summary obtained from analysis, it is found that quadratic model is statistically significant for Modulus of Rapture. The results of the quadratic model for specific strength in the form of ANOVA are presented in Table 5. If the F value is more corresponding p value must be less, resulting in a more significant corresponding coefficient. Non significant terms are removed by backward elimination for the fitting of specific strength in the model. Alpha out value is taken at 0.05 (i.e., 95 % confidence level). If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. It is found from Table 5 that F value of the model is 31.00 and related p value is <0.0001, results of a significant model. The lack of fit is a measure of the failure of the model to represent data in the experimental domain at which points are not included in the regression variations in the model that cannot be accounted for by random error. If there is a significant lack of fit, as indicated by a low probability value, the response predictor is discarded. The Model F-value of 31.00 implies the model is significant.

Std. Dev.	1.00	R-Squared	0.9894
Mean	45.33	Adj R-Squared	0.9574
C.V. %	2.21	Pred R-Squared	0.7846
PRESS	40.50	Adeq Precision	14.741

Table 5 : Regression co-efficient for MoR

The "Pred R-Squared" of 0.7846 is in reasonable agreement with the "Adj R-Squared" of 0.9574, i.e. the difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 14.741 indicates an adequate signal. This model can be used to navigate the design space.

Constraints							
		Lower	Upper	Lower	Upper		
Name	Goal	Limit	Limit	Weight	Weight	Importance	
A:A	is in range	Level 1 of A	Level 3 of A	1	1	3	

B:B	is in range	Level 1 of B	Level 3 of B	1	1	3	
D:D	is in range	Level 1 of D	Level 3 of D	1	1	3	
R1	maximize	39	52	1	1	3	

Table 6: Optimization Report

Number	A	B	C*	D	R1	Desirability	
1	Level 3 of A	Level 3 of B	Level 1 of C	Level 1 of D	51.66667	0.974359	Selected
2	Level 3 of A	Level 2 of B	Level 1 of C	Level 1 of D	51	0.923077	
3	Level 3 of A	Level 1 of B	Level 1 of C	Level 1 of D	50.33333	0.871795	
4	Level 3 of A	Level 3 of B	Level 1 of C	Level 3 of D	50.33333	0.871795	
5	Level 3 of A	Level 2 of B	Level 1 of C	Level 3 of D	49.66667	0.820513	
6	Level 3 of A	Level 3 of B	Level 1 of C	Level 2 of D	49	0.769231	
7	Level 1 of A	Level 3 of B	Level 1 of C	Level 1 of D	49	0.769231	
8	Level 3 of A	Level 1 of B	Level 1 of C	Level 3 of D	49	0.769231	
9	Level 3 of A	Level 2 of B	Level 1 of C	Level 2 of D	48.33333	0.717949	
10	Level 1 of A	Level 2 of B	Level 1 of C	Level 1 of D	48.33333	0.717949	
11	Level 3 of A	Level 1 of B	Level 1 of C	Level 2 of D	47.66667	0.666667	
12	Level 1 of A	Level 1 of B	Level 1 of C	Level 1 of D	47.66667	0.666667	
13	Level 1 of A	Level 3 of B	Level 1 of C	Level 3 of D	47.66667	0.666667	
14	Level 1 of A	Level 2 of B	Level 1 of C	Level 3 of D	47	0.615385	
15	Level 1 of A	Level 3 of B	Level 1 of C	Level 2 of D	46.33333	0.564103	
16	Level 1 of A	Level 1 of B	Level 1 of C	Level 3 of D	46.33333	0.564103	
17	Level 1 of A	Level 2 of B	Level 1 of C	Level 2 of D	45.66667	0.512821	
18	Level 1 of A	Level 1 of B	Level 1 of C	Level 2 of D	45	0.461538	
19	Level 2 of A	Level 3 of B	Level 1 of C	Level 1 of D	41.33333	0.179487	
20	Level 2 of A	Level 2 of B	Level 1 of C	Level 1 of D	40.66667	0.128205	
21	Level 2 of A	Level 1 of B	Level 1 of C	Level 1 of D	40	0.076923	
22	Level 2 of	Level 3 of	Level 1	Level 3	40	0.076923	

	A	B	of C	of D			
23	Level 2 of A	Level 2 of B	Level 1 of C	Level 3 of D	39.33333	0.025641	
*Has no effect on optimization results.							

Table 7: Solutions for 23 combinations of categoric factor levels

6.0 Observation and Conclusion:

From Table 7, we can interpret that the most desirable combination of factors are as follows:

The first combination, which has a desirability percentage of 97.44 should be set at temperature of 150° C, a pressure of 16 Kgf/cm², press time of 20 minutes and glue consumption at the rate of 180 gm per square ft. The second combination can be set at temperature of 150° C, a pressure of 15 Kgf/cm², press time of 20 minutes and glue consumption at the rate of 180 gm per square ft. The second combination has a desirability of 0.923077. The third and fourth combinations have same desirability percentage of 87.18 should be set at either at temperature of 150° C, pressure of 14 Kgf/cm², press time of 20 minutes and glue consumption at the rate of 180 gm per square ft or at temperature of 150° C, pressure of 16 Kgf/cm², press time of 20 minutes and glue consumption at the rate of 240 gm per square ft.

The present investigation has been done taking four controllable parameters or variables as input factors. There are total twenty one variables so far identified by the researchers, which play major or minor roles in the property of finished plywood product. Further study can be done taking five or more parameters as input factors at a time to determine their interaction or simply taking other variables. Similarly investigations can be made taking Modulus of Elasticity, Wood Failure, Biological resistance, Glue strength and other mechanical test parameters as output responses. Level of factors can be changed suitably and significant factors can be identified

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