Development Of Second Order Univariate Regression Model For Estimating Impact Of Blending Softwood With Hardwood And Bamboo With Hardwood Pulps For Improving The Paper Properties.

Chauhan Ajay & Ghosh U.K.

IIT Roorkee, Saharanpur Campus, Department of Paper Technology, Saharanpur - 247001 (U.P.)

ABSTRACT

The present research deals mainly with the physical and mechanical strength properties of pulp stock paper, viz tensile, tear, burst and density/bulk obtained by blending different proportions of hardwood with softwood and bamboo pulps. The 2nd order univariate polynomial regression models were developed by the least square technique using various results. The bleached short fibre mixed hardwood pulp (Eucalyptus tereticornis and Populus alba) was collected from Paper Mill A, imported softwood pulp Pinus roxburghi and bamboo pulp from Mill B. The initial °SR of all the pulps was same 28. Various blends in the proportion of 100:0, 92:8, 88:12, 84:16, 80:20, 76:24, 72:28, in terms of percentage of hardwood with other pulps respectively were prepared and various pulp and paper properties of the above blends have been determined using TAPPI standard procedure.

Various results were analyzed and optimized with help of developed model and it is found out from the model, that the error is having 5% of level of significance. Various graphs show that strength properties are obtained from blend with SW-HW in ratio 8:92, 12:88 are quite similar to blend with Bamboo-HW and it shows that the bamboo is a suitable alternate of softwood for strength properties.

Key Words: *blending, least square technique, curve fitting, univariate regression.*

Introduction

Indian pulp and paper industry faces the problem of procuring suitable raw material for producing the desirable properties of paper. For fulfilling these demands they must rely upon different kind of pulps (which can be easily available) to achieve the desirable properties in the paper. Due to increased availability of recycled paper, limited hardwood resources and their regional distribution and also abundant non-wood resources, the required properties of paper cannot be achieved unless a stronger and longer fibre pulp is used along with the indigenous material. In our country, the raw materials are mainly short fibred but they still compensate for the shortage of raw materials. But in this competitive world, quality is the major concern, so these short fibres are suitably blended with long fibred stock to attain the desirable properties of pulp. In fact, both type of pulps (softwood and hardwood) have their unique and distinct properties and their furnish value is also different. On the other hand, the mixture of the different fibres is inevitable in the present day scenario of Indian pulp and paper industry. Indian Paper Industry mainly relies upon the mixed wood fibres because of the following reason. The indigenous raw material (hardwood fibre) has good bulk and more fibre fines which make paper bulkier, smoother and also gives greater yield. While on other part the softwood fibre has greater length and greater surface area is available for more fibre to fibre bonding. The softwood pulp suitably mixed with the hardwood pulp enhances the strength and formation of paper while getting good yield. On blending of pulp, the regression models were developed in microscopic level to calculate the apparent density of the sheet as a function of blend composition and fibre properties. The multiplanner model developed by Görres et. al. [5] assumes that

(a) Paper is a superimposition of fibre layers,
(b) The layer mass is a function of fibre width and coarseness and is given in one point when 1% of the network area is covered by fibre crossings,
(c) The layer structure is described adequately by network statistics,
(d) Translayer bonding occurs when fibres are deflected by wet pressing, and
(e) The average fibre properties are sufficient to describe the sheet structure.

To compute the mean fibre properties of blend, the fibre properties of each pulp are weighted by the fraction of total fibre length that the individual pulps contribute to the sheet. In the area of blending of fibres prediction of various properties of pulp and paper in macroscopic level very less work was done. Ray et. al. [2] tried to model the effect of blending on optical and surface properties. They have developed a regression equation for interaction of blend percentage, amount of filler and amount of size added in a blend furnish on the different properties, and scattering developed was a three parameter nonlinear regression equation of the form.

$$Y=B_0+B_{1.}X_1+B_{2.}X_2+B_{3.}X_3+B_{12.}X_{1.}X2+B_{13.}X_1.X_3+B_{123.}X_{1.}X_2.X_3$$

This gives the idea about how the properties related to each other by blending. Firstly experimental procedure was done by statistics [1], then the experimental work is carried out finally and obtained data was used to develop the correlation equations for different properties of the paper formed by making different blends.

Background Literature

In India to manufacture paper with desirable quality, it is necessary to blend different kind of pulps. By empirical models [6], we can easily select pulps and determine the best blend compositions for a particular paper making applications. Blending models are either based on principle of property additivity or regression analysis [3].

There are two types of nonlinear behavior which may occur

1. Synergism

When pulp component interacts and results in the property of blends which is better than the sum of the contributions of each individual components and this can be weighted according to the fraction of the total mass of mixture contributed by individual components.

2. Antagonism

It can be the case when property of blend is inferior to the sum of weighted contributions of individual components. For practical purpose, the antagonism means that the values fall below than the value predicted by additivity and synergism [7].

Quality of fibre required for the production of paper.

The Eucalyptus and Poplar pulps are the raw materials for the manufacturer of several grades of paper. For each grade, the pulp quality required is as per industries requirement. This means that there is no universal pulp which is available everywhere. Some of the properties depends mainly upon the wood quality, others depend upon the conversions into wood to pulp, and many are the combinations of these two factors influencing the pulp quality. For example some properties related to pulping and bleaching are: viscosity and degradation of cellulose fibre-fibre deformation as well as individual fibre strengths, and surface charge on the fines etc. One more important property is the hemicellulose content in the pulp for determining water retention value.

Mixed hardwood pulp and fibre properties

The following properties parameters can distinguish the different types mix hardwood fibrous raw materials and to allow pulp furnish optimizations.

Mix hardwood paper products

Bulky and opaque papers are produced by Eucalyptus and poplar pulps. Now a day these pulps are used for production of printing and writing, tissue, carton boards, industrial filter, base-paper for impregnation or coating, cigarette etc. Mix hard wood fibres are sole fibre in the pulp furnishes and also be a part of blend with long fibres [4].

Usage of softwood pulp

Softwood fibre is the heterogeneous raw material for paper making. The morphology of wood affects the length and the cell wall thickness (CWT) distributions of fibres. Tracheid growth during spring and summer is very different. This result, the CWT of latewood fibres is greater in length than that of early wood fibres, this makes latewood fibres less flexible. Tracheids of latewood are also often longer [5]. Difference in fibre dimensions leads the manufacture of different grade of papers or paperboards. Improved strength may be a desirable property. But at the same time other properties such as smoothness, long and stiff fibre improves bulk and decreases density but impair its strength but have negative impact on smoothness and surface properties. It shows that there is the need in improvement and controls over fibre properties for betterment of papermaking process to meet increased qualities.

For blending of the pulp the refining is the important process which provides greater surface area to the fibre-fibre bonding. This may lead to fibre flocculation in the refining [8]. An increase in the inter fibre bonding increases the formation of coherent flocs which resist rupture in the flow, which changes the randomness in the suspension. At the point of contact between fibres several types of cohesive forces exist and due to this fibre properties may differ. For eg. fibre length, fibre surface, fibre stiffness and fibrillation action affect the magnitude of mechanical surface linkage and elastic fibre bending [7]. Different gap widths for the short and long fibre pulps have been reported [11] and also the work on Chip blending resulted in faster decrease of tear index than pulp blending is already reported [12].

Bamboo

Earlier bamboo strips were used in china for writing purpose. Bamboo pulps are mainly produced in Asian countries and are used in different grades of papers. The average fiber length of bamboo is similar to hardwoods, but the properties are similar to softwood pulps due having a very broad fiber length distribution [9]. Bamboos are some of the fastest growing grass in the world [5], as few species have been recorded as growing up to 100 cm (39 in) within a 24 hour period due to a unique rhizome-dependent system, and the work on Fiber fractionation followed by the selective processing of each Bamboo-HW produces improved quality of paper is already reported [10].

Experimental Procedure

Experimental design

Pulp samples

All the pulp fibres were separately treated in the Valley beater at 1.5% consistencies to attain °SR of 28 (HW, SW, and Bamboo).

Evaluation of pulp and pulp blending the two pulps were blended in several combinations of HW-SW and HW-Bamboo proportions, mixing always the samples as 0-100, 8-92, 12-88, 16-84, 20-80, 24-76 and 28-72 respectively. Slurries of each blend were prepared. The slurries were well stirred to ensure a uniform distribution of the fibres of the two mixed pulps. The various readings for the freeness of all the blends were measured and also subjected to statistical regression in relation to the proportion of soft wood used.

Handsheet forming and paper testing

In all experiments, standard handsheets with a grammage of 75 gsm were made on a British sheet mould according to **TAPPI** standard T-205 cm-80. The blended handsheets were subsequently tested for physical properties after conditioning at 27±2 °C and 65±2 % relative humidity. A summary of applied methods and standards is listed in **Table 1**.

Results and Discussions

The results show the quality of pulps used in the study, papermaking properties of their blends and regression equations enlightening the relationships between different pulp and paper properties. As the fibre swells the water bounded with the fibres increases this may lead the WRV values in the fibre, so here in the fig. (1a&1b) is the fibre distributions present into the bamboo-HW blend is less but the surface available in the case of SW-HW blend more to swell . Water retention value more in the case of SW blend.

Effect of blending on Drainage Time

Drainage time fig. (2a&2b) increases with the increase of fibre distribution after refining present in the pulp, so fibre length content in SW blend are larger than bamboo blend which shows that the drainage time less in the case of SW blend.

Table 1: Standards used for measurement of various properties.

S. No.	Properties	Standards
1	GSM	T 410 OM-02
2	Thickness	T 551
3	WRV	UM 256
4	Drainage time	T 221 cm-09
5	°SR	T 227 OM-99
6	Tensile strength	T 456 OM-03
7	Tear strength	T 414 OM-98
8	Bursting strength	T 403 OM-02

Table 2: Details of various pulp blends studied

S.No.	Blend Ratio	
	SW-HW	Bamboo-HW
1	0:100	0:100
2	8:92	8:92
3	12:88	12:88
4	16:84	16:84
5	20:80	20:80
6	24:76	24:76
7	28:72	28:72

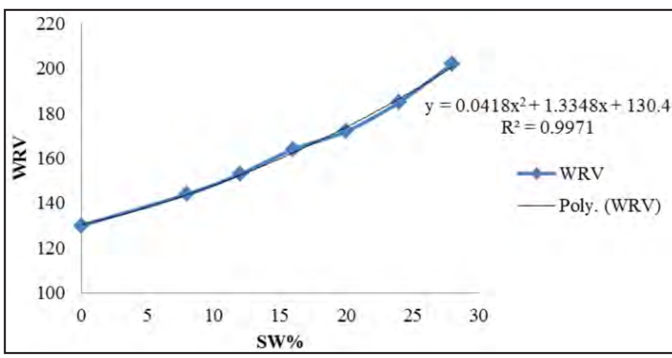


Fig 1 (a) WRV vs. % of SW in the blend of SW-HW

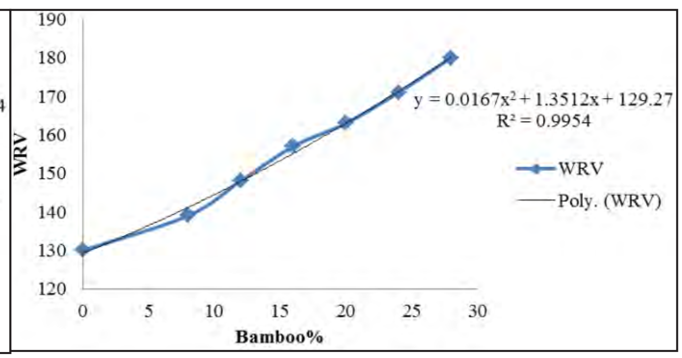


Fig 1 (b) WRV vs. % of Bamboo in the blend of Bamboo-HW

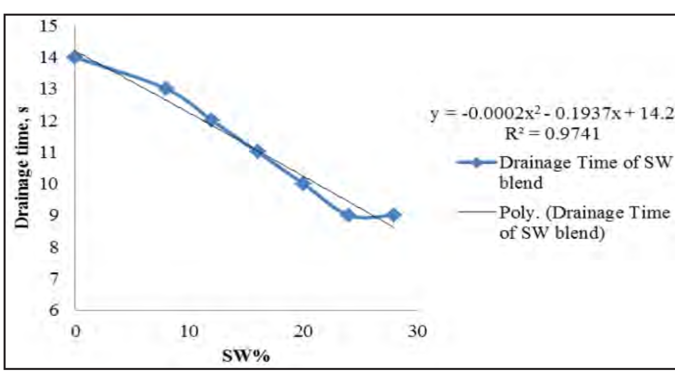


Fig 2 (a) Drainage time vs. % of SW in the blend of SW HW

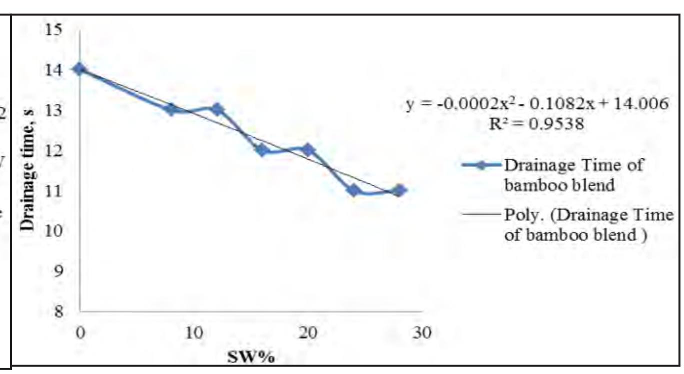


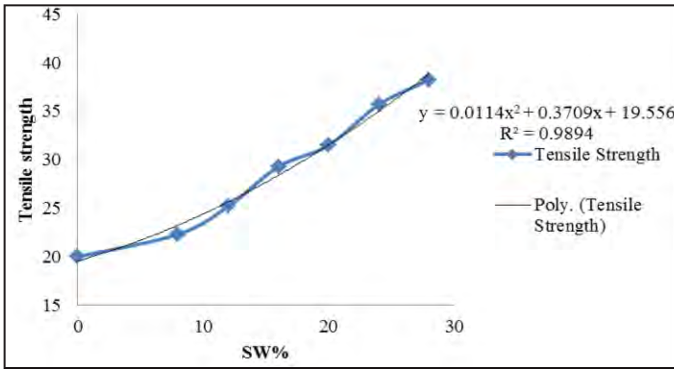
Fig 2 (b) Drainage time vs. % of Bamboo in the blend of Bamboo-HW

Effect of blending on Tensile strength

Increase in tensile strength in fig. (3a&3b) shows good beating and its decrease shows that more refining done during beating. Tensile strength increases in both the cases but higher in the case of SW blend due to presence of higher surface area available for bonding.

Effect of blending on Tear strength

Tear strength in fig. (4a&4b) increases in both cases and bamboo blend has almost same kind of increase in the tear strength as SW blend, but bamboo blends having the values which are only slightly less than SW blend.



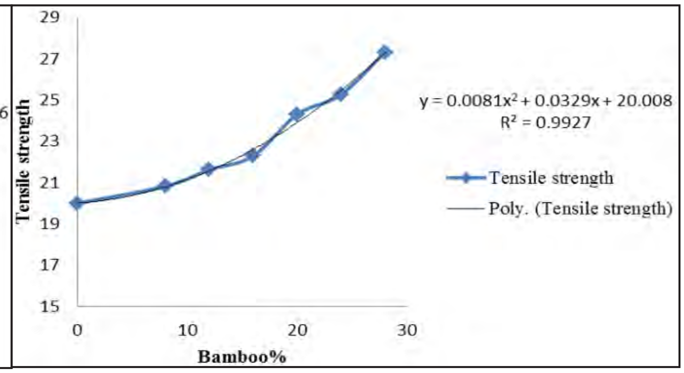
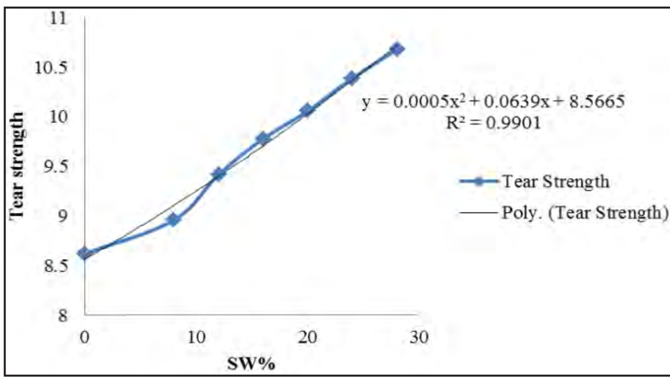


Fig 3 (a) Tensile Strength vs. % of SW in the blend of SW HW Fig 3 (b) Tensile Strength vs. % of Bamboo in the blend of Bamboo HW



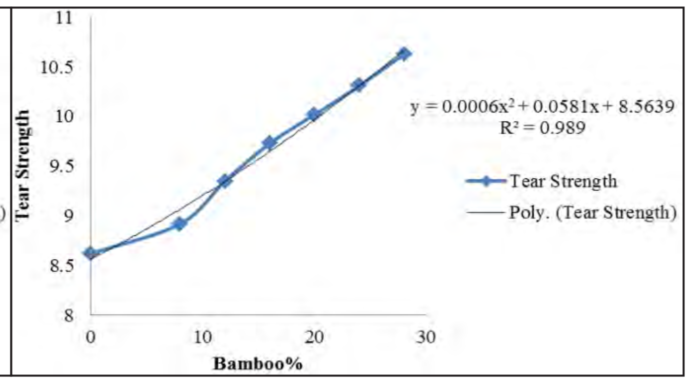


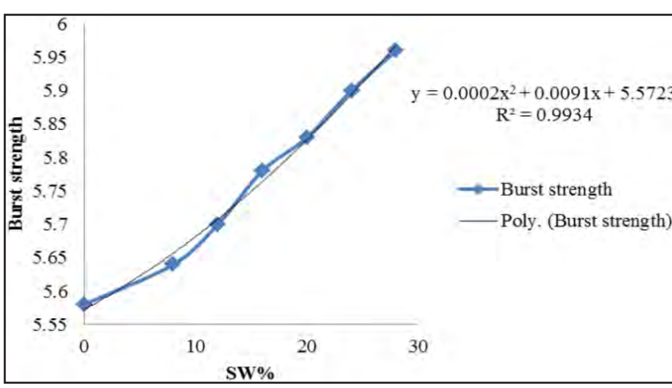
Fig 4 (a) Tear Strength vs. % of SW in the blend of SW -HW Fig 4 (b) Tear Strength vs. % of Bamboo in the blend of Bamboo HW

Effect of blending on Burst strength

Similarly Burst Strength in fig. (5a&5b) also increases in this case but SW blend, but bamboo blend having the values which are slightly less than SW blend.

Statistical Interpretation of Data

Experimental data obtained from the laboratory are analyzed from graphs and the regression model was developed with the help of least square technique. For simplicity the linear and polynomial regression have been used for, analysis according to applicability of the data. Some of data having linear characteristics and some are nonlinear. Predicted data from regression equation plotted against the experimental values in various graphs and percentage errors have been determined.



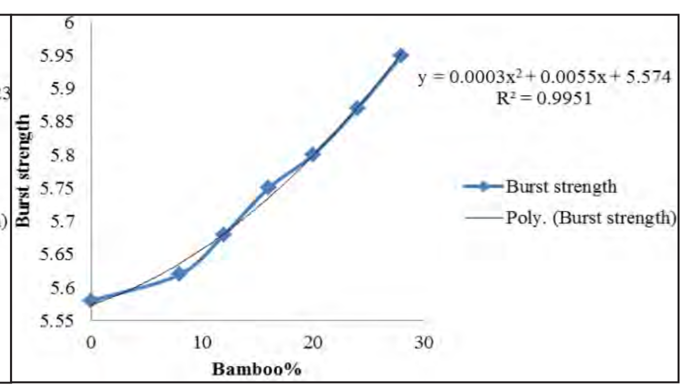


Fig 5 (a) Burst Strength vs. % of SW in the blend of SW HW

Fig 5 (b) Burst Strength vs. % of Bamboo in the blend of Bamboo-HW

Table 3: Second order univariate polynomial model equations and R^2 values for different properties of blends

S.No.	X, blend of	Y, properties	2^{nd} order Univariate Polynomial Model	Value of R^2
1.	SW-HW	WRV	$y = 0.0418x^2 + 1.3348x + 130.4$	$R^2 = 0.9971$
	Bamboo-HW	do	$y = 0.0167x^2 + 1.3512x + 129.27$	$R^2 = 0.9954$
2.	SW-HW	Drainage time	$y = -0.0002x^2 - 0.1937x + 14.2$	$R^2 = 0.9741$
	Bamboo-HW	do	$y = -0.0002x^2 - 0.1082x + 14.006$	$R^2 = 0.9538$
3.	SW-HW	Tensile Strength	$y = 0.0114x^2 + 0.3709x + 19.556$	$R^2 = 0.9894$
	Bamboo-HW	do	$y = 0.0081x^2 + 0.0329x + 20.008$	$R^2 = 0.9927$
4.	SW-HW	Tear Strength	$y = 0.0005x^2 + 0.0639x + 8.5665$	$R^2 = 0.9901$
	Bamboo-HW	do	$y = 0.0006x^2 + 0.0581x + 8.5639$	$R^2 = 0.9890$
5.	SW-HW	Burst Strength	$y = 0.0002x^2 + 0.0091x + 5.5723$	$R^2 = 0.9934$
	Bamboo-HW	do	$y = 0.0003x^2 + 0.0055x + 5.574$	$R^2 = 0.9951$

% error = [(e.v. m.p.v.)/ (e.v)] *100

Where e.v.= experimental value.

m.p.v. =model predicted value.

The entire regression models given in **table 3** which are developed are very accurate as the regression coefficient, R^2 are close two unity on avg. of 0.987 and the percentage error does not exceed ±5%. The model predicted data (MPD) and the experimental data (ED) are compared with the graphs. The detailed graphs are also showed and summarized in the **table 4**. The plot between MPD vs. ED shows the excellent agreement between two. Therefore statistically analysis predictions claimed to be very good reasonable degree of accuracy permitting in engineering estimates. This can be used reliably for analysis purpose.

Table 4: EV and MPV values of WRV for SH-HW blends

S.No.	EV	MPV of WRV	Error%	Residual (eij)
1	130	130.4000	-0.30769	-0.400
2	144	143.7536	0.171111	0.2464
3	153	152.4368	0.368105	0.5632
4	164	162.4576	0.940488	1.5424
5	172	173.8160	-1.05581	-1.816
6	185	186.5120	-0.81730	-1.512
7	202	200.5456	0.720000	1.4544

From the above all observations we can say that the fibre length as well as surface area plays important role in the bond formation with and within the fibres by providing large surface area and surface charge for binding. This will result in the more no. of bonds due availability of higher surface area of SW & bamboo pulp fibre.

Fig. (6) Depicts the relation between EV and MPD the above pulp blend at WRV vs. SW%. It has error between -1.06 to +0.95.It is evident from

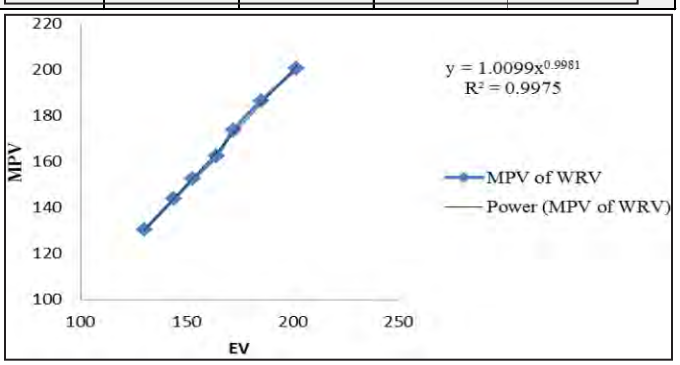


Fig 6: The EV vs. MPV for pulp blend SW-HW (WRV)

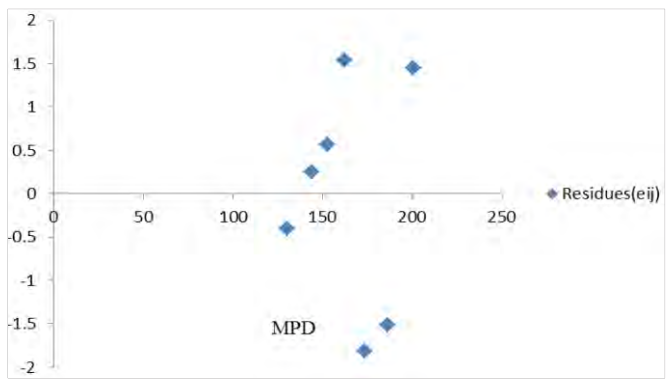


Fig 7: Residuals vs. MPV for pulp blend SW-HW (WRV)

Table 5: Residual analysis and % errors in different properties of SW-HW and Bamboo-HW blends

S.NO.	Type Of blend	Properties	ERROR%	Residual Analysis
1	SW-HW	WRV	-1.06 to +0.95	-1.82 to +1.55
		Drainage Time	-4.85 to +4.23	-0.44 to +0.39
		Tensile strength	-4.18 to +3.05	-0.94 to +0.9
		Tear strength	-1.68 to +0.65	-0.15 to +0.07
		Burst strength	-0.41 to +0.19	-0.41 to +0.19
2.	Bamboo-HW	WRV	-1.55 to +1.17	-2.15 to +1.84
		Drain Time	-2.68 to+2.48	-0.3 to +0.33
		Tensile strength	-1.43 to +1.63	-1.43 to +1.63
		Tear strength	-1.65 to +0.86	-0.15 to +0.09
		Burst strength	-0.31 to +0.2	±0.02

the plots that EV vs.MPD ...rees to high degree of ...curacy.

... (7) Examine the ...avior of the residuals ... a function of MPD of ... above parameters. It ... found that plot is ...ucture less and ...sidues are found ...ween -1.82 to +1.55, ...s is distributed around ...o. So this is best ...diction.

Similarly we can compare all the properties and fit the curves which derived from various properties with changing the concentration of SW-HW blend as well as bamboo-HW pulp. The various comparisons of EV and MPD, and residual analysis given in the **table 5** and we also draw the result obtained from the **table 5** that level of significance from the data does not exceed from 5% and the second order regression model is perfect fit.

Conclusions

From the above detailed analysis of data, graphs as well as from tables, the following conclusions can be made. Model Developed here are more accurate and good for Engineers estimation as well as for Paper technologist. Percentage error is having 5% of level of significance. From the various graphs it is observed that the strength properties increase with blend of long fibre with hard wood pulps. In the research it finds out that those strength properties are obtained from blend of SW-HW in ratio of 8:92, 12:88 are quite similar to blend of Bamboo-HW in ratio of 20:80, 24:76. Regression equations agrees excellently with the experimental data with regression coefficient tends towards unity. From residuals analysis the unstructured plots obtained that are very close towards zero. For obtaining better strength properties suitably prepared blend of the short fibre pulp with the long fibre pulp and the model developed here can be used to know how the properties are changing with changing blend %. The model developed here 2nd order Polynomial Regression Model is a perfect fit.

References

1. Ray AK, Rajesh D, and Krishnan R, A project report on: “Role of blending on paper properties-A statistical evaluation”, D.P.T., IIT Roorkee, (1995-96).

2. Ray AK, Srivastava S, and Sharma A, A Project Report on: “The Optical and surface properties of paper based on blending non wood fibre with long fibre pulp”, D.P.T., IIT Roorkee.

3. Görres A, Wood JR, and Karnis A, International Paprican report MR 173, (1990).

4. Brecht W, Svensk Paperstid 66 (5): 159, (1963).

5. Göreres J, Amiri G, Wood JR, and Karnis, A, Tappi Journal . Vol 79 (1),179-187, (1996).

6. Karkkainen M, and Metasalehti K, Hämeenlinna., “Principle of wood science” in finnish. 22-25, (2003).

7. Kerekes R J, Soszynski RM, and TamDoo PA, “The flocculation of the pulp fibres”. In: Papermaking rawmaterials , Edited V. Punton. Mechanical Engineering Publications Limited 265-310, (1985).

8. Levlin JE and Paulapuro, H Papperi, and Ja, Puu, 69 (5), 410, (1987)

9. Nanko H, Button A, and Hillman D The World of Market Pulp. Appleton, WI, USA: WOMP, LLC. 256. ISBN 0-615-13013-5, (2005).

10. Tyagi S, Godiyal RD, Kumar Manoj, Thapiyal BP, and Mathur RM, “Fiber Fractionation- A unique Technique for making quality paper from indigenous Raw materials”, IPPTA , 24 (1) , 177-181, (2012)

11. Watson AJ, Phillips FH, and Cohen WE, “Beating characteristics of mill”, Eucalyptus pulp. Appita 16 (3), 71-89, (1962).

12. Zhibin H, Younghao Ni, and Yajun , Mixed chip pulping. Bioresourses, 5 (4). 2625-2639, (2010).