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APPLICATION OF PRINCIPLE COMPONENT ANALYSIS FOR THE IDENTIFICATION OF SIGNIFICANT PARAMETERS INFLUENCING BRONZE COATING QUALITY IN WIRE COATING PROCESS OF TYRE BEAD WIRE

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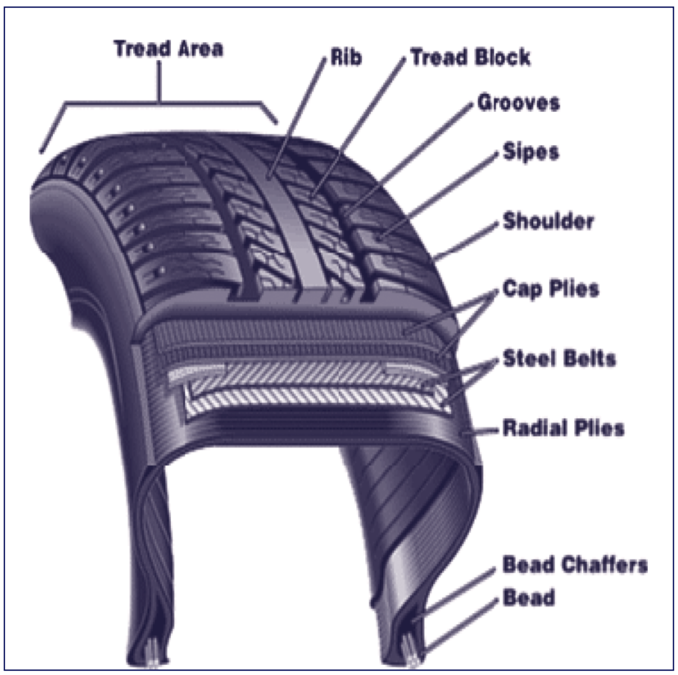
Abstract:

The process of applying bronze coating on tyre bead wire is a multistage process involving multiple variables at each stage. Variables at each stage may potentially influence the quality of coating on the wire. The entire process constitutes a complex multivariate system, hence it becomes a challenging task to identify which variables are really significant for the quality of the coating. The Current paper demonstrates the application of multivariate analysis tool known as Principle Component Analysis for the identification of few significant variables from a multivariate process. Once the significant variables are identified, they can be used for multivariate modeling and optimization of the response under study i.e. coating quality.

1 INTRODUCTION

Tyre bead (Fig 1-1) is the term for the edge of a tyre that sits on the wheel. Wheels for automobiles, bicycles, etc. are made with a small slot or groove into which the tyre bead sits. When the tyre is properly inflated, the air pressure within the tyre keeps the bead in this groove. The main

Figure 1-1: Structure of Tyre Bead

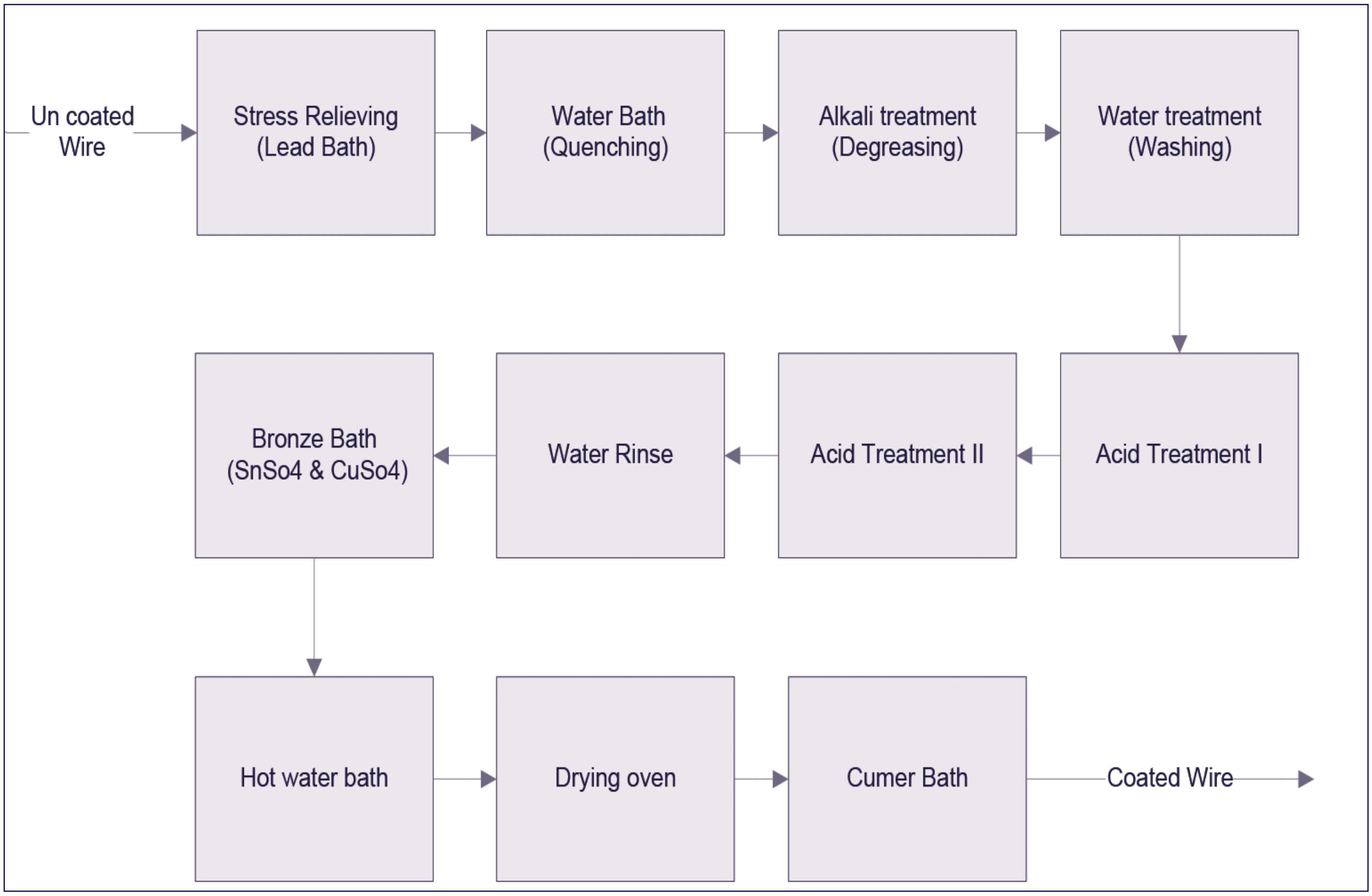


function of bead wire is to hold the tyre on the rim and to resist the action of the inflated pressure, which constantly tries to force it off. It also helps to get a proper grip of the tyre on the rim. Bead wire is the vital link through which the vehicle load is transferred from the rim to the tyre, which prevents vibration during driving[1][2]. It significantly affects the safety, strength and the durability of tyres. The tyre is subjected to high pressure and heat during running due to which the rubber will have the tendency to separate from the wire which may lead to bead failure. Bead failure during vehicle running may cause tyre burst and sometime may become fatal. The resistance to the separation of rubber from wire is offered by the adhesive force between the rubber and the tyre bead. A special bronze coating on the wire surface is responsible for the adhesion between rubber compound and wire.

The adhesion between rubber and bead wire mainly depends upon the composition of bronze coating on the surface of bead wire. The bronze coating on the wire consists of copper (Cu) and Tin (Sn). The Sn% by weight in the coating is critical for the adhesion strength of the wire. For the tyre bead application, allowable limit of Sn% by weight in the tyre bead is 1-3% [3]. A Small variation of the Sn% in coating can significantly reduce the adhesion strength of wire which may result in separation of rubber from the wire bead during the running condition. This may lead to a serious accident of the vehicle during running.

In order to achieve desired coating quality, it is necessary to identify the important parameters of the coating process and control them. The process of wire coating is a complex system involving multiple variables (Fig 1-2); identification of important parameters contributing to coating quality is a challenging task. Normally traditional statistical tools (univariate and bivariate) are used for the analysis and identification of significant variables in a process; however, their application in a multivariate scenario may be time consuming, offer some complexities and may lead to loss of some vital information. The current paper uses multivariate analysis tools for the identification of significant variables from the coating process. Later, the traditional analysis tools have also been used to perform the same task. A comparison between the use of multivariate analysis tools and traditional analysis tools for the same task is also presented and discussed.

Figure 1-2: Wire Coating Process Flow



2 LITERATURE REVIEW

Adhesion between rubber and steel wire takes place during the process of vulcanization of the tyre which provides the interfacial strength. For the adhesion of wire, chemical/ electrochemical bond formation is of the prime importance . Alloy of Copper with Zinc (Brass) coating has already been established for industrial applications as the carcass of tyres, popularly known as steel tyre cord[4]. Effect of Sn on the Adhesion between Cu–Sn Alloy Coated Steel and Styrene Butadiene Based Rubber has been studied by Atanu Banerjee *et al, 2013*. Sn content in the Cu–Sn coatings was varied from 3–6.5 % by varying the SnSO4 content in the electrolyte bath. The results of Peel test revealed that the highest interfacial adhesion strength was obtained for 3 to 4 wt% Sn in coating.

An article by W. J. van Ooij [5] reported the adhesion model, bonding mechanism, the role of different additives in rubber, effect of aging at interface bonding, different metal surface pretreatments and advanced ternary coatings like Cu–Zn–Co/ Ni on steel wire. van Ooij, the coating on steel wire reacts with sulfur (added as a curing agent in rubber) forms an interfacial layer predominantly consisting of sulfide. This sulfide layer facilitates the adhesion of bead wire by mechanical and/ or chemical interaction with the cured rubber. The coating composition of the steel wire is extremely crucial and has to be optimized to support the specific requirements of the sulfide layer formation synergizing with the curing cycle of the rubber D. A. Stout *et al. [6]*.

Pearson in 1901 developed Principle component analysis, which has been successfully adapted to various industries to create summary information. Data analysis methods dealing with only one variable at one time are known as univariate methods. These methods often turn out to be of limited use in more complex data analysis. Mastering univariate methods are still necessary, however, as they carry limited information of a complex system, are insufficient for a complete data analysis. Principle component analysis (PCA) is basically an exploratory data analysis. It is a way of identifying patterns in data, and expressing the data in such a way as to highlight their similarities and differences, Kim [7].

PCA involves decomposing one multivariate data set into a “structure” part and a “noise” part. It is a bilinear modeling method that provides an interpretable overview of the main information contained in a multidimensional table. It takes information carried by the original variables and projects them onto a smaller number of latent variables called *Principal Components (PC)*. By plotting PCs important sample and variable interrelationships can be revealed, leading to the interpretation of certain sample groupings, similarities or differences [8].

Jolliffe IT [9], Highlighted the need for dimensionality reduction in an interpretatble way so that most of the information from the data can be extreacted. Interpretation of principle component model using various plots has been done with a multivariate data having 88 samples and. 9 variabes

H. Eastment *et al.* [10] suggested method to choose the optimal number of components to retain in a principal component analysis when the aim is dimensionality reduction. The correspondence between principal component analysis and the singular value decomposition of the data matrix is used. The method explained by them is based on predicting successively each element in the data matrix after deleting the corresponding row and column of the matrix, and makes use of recently published algorithms for updating a singular value decomposition.

Shlens [11], in a tutorial provided an intuitive explaination of goal of PCA taking a simple example of a system of mass attached to a spring and measuring the ball positions at different times using three camaras placed in three dimensional space. Algebraic solutions for PCA like eigenveactors and singular value decompositions (SVD) are explained.

Ken Black [12], explained statistical tools for exploration of information from the data set. The concepts of scatter plots and correlation coefficient have been explained to find out the correlation structure and strength of correlation between two variables.

3 PROPOSED METHODOLOGY

In this paper, various plots of principle component analysis have been used as a multivariate analysis tool to identify the significant variables from the coating process. The scatter plot and correlation analysis have been used as the univariate tools for the identification of significant variables from the coating process. The steps to be taken are explained below.

a. Study the stages of the coating process and identify the list of potentially influencing process variables (process parameters) for the coating quality (Sn% by weight in the coating).

b. Conduct the trials for around 15 days and measure each process parameter along with corresponding %Sn in the wire.

c. Analyze the data collected during the trial using the score and loading plots of principle component analysis and identify the significant parameters contributing to the Sn% in wire coating.

d. Analyze the same data using scatter plot and correlation coefficient between each variable and identify the significant parameters contributing to the Sn% in wire coating.

e. Compare the results of step ‘c’ and ‘d’ and comment.

%Sn by weight in the wire coating is measured using an XRF spectrometer, which is a non-destructive analytical technique. XRF analyzers determine the chemistry of a sample by measuring the fluorescent (or secondary) X-ray emitted from a sample when it is excited by a primary X-ray source. Each of the elements present in a sample produces a set of characteristic fluorescent X-rays that is unique for that specific element, which makes XRF spectroscopy is an excellent technology for qualitative and quantitative analysis of material composition.

4 DETERMINATION OF POTENTIAL PARAMETERS

The various stages of coating process are shown in the Fig 1-2. A thorough study of the entire coating process has been done. An approach of failure mode and effect analysis (FMEA) has been utilized to analyze each step of the coating process with respect to its contribution to the performance of the bronze coating on the wire.

Table 4-1: List of Potential Parameters

Opn No	Operation	Potential Paraneters
1	Stress releiving in lead bath	Lead Bath I temperature
		Lead Bath II temperature
		Lead level in the bath
2	Degreasing in alkali batl	Bath temperature
		Alkali Conc
		Rectifier voltage
3	Pre acid cleaning (HCL-	HCL-I concentration
4	Post acid cleaning (HCI	HCL-II concentration
		HCL-II temperature
5	Water rinse	pH of water
6	Bronze coating	CuSo4 concentration
		SnSo4 concentration
		Free Acidity
		Bath temperature
7	Hot water rinse	Hot water temperature
		TDS of hot water
		pH of hot water
8	Drying	Temperature of drying oven
9	Cumer coating	Cumer concentration

A list of process parameters potentially influencing the Sn% in the wire has been derived using FMEA approach [13]. FMEA is a risk analysis tool which is widely adopted in the automotive industries for the risk analysis of manufacturing processes and products. With this risk based strategy, important characteristics of manufacturing process and products are determined [14]. The summary of the process FMEA output for coating process has been presented in Table 4-2. The parameters identified by the FMEA have been listed in Table 4-1. Total 19 process parameters from various stages of the wire coating process have been identified. Once the potential parameters have been determined, the trials have been conducted for around 15 days. All the identified process parameters have been measured during the production of each coil of the wire and corresponding value of Sn% in wire has also been measured in the samples taken from each coil.

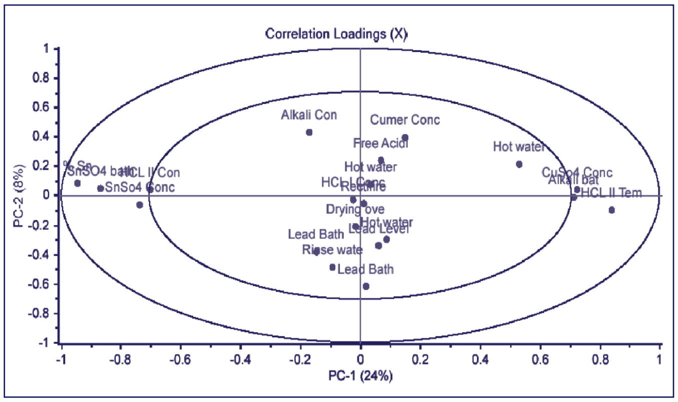
Table 4-2: Summary of PFMEA

Process Step	Process Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Potential Cause(s) of Failure
Stress relieving in lead bath	Reduce internal stresses in the wire	Internal stresses not reduced	Bead failure resulting into reduced tyre life	Bath temperature not maintained
	Achieve required elongation	Required elongation not achieved	Bead failure resulting into reduced tyre life	Bath temperature not maintained
	Achieve required break load	Required breakload not achieved	Bead failure resulting into reduced tyre life	Bath temperature not maintained
	No lead carry over	More lead carry over	Improper cleaning at subsequent stage resulting into non uniform coating and low adhesion leading to reduced tyre life	Lead level in the bath not maintained
Water Quench ing	Cool wire to specified temperature	Wire doesn't cool to required temp	Improper cleaning in electrolyte tank resulting into low adhesion and reduced tyre life	Temperature of bath not maintained
				pH of water ot maintained
	Partial cleaning of wire	No cleaning of wire	Overloading of alkali bath lead to improper cleaning resulting into improper coating resulting into reduced adhesion and reduced tyre life	Temperature of bath not maintained
				pH of water ot maintained
Alkali Degreasing	Clean the surface of wire to make it free from lubricant	Wire surface not cleaned	Reduced adhesion due to improper coating resulting into reduced tyre life	Alkali concentration not maintained
				Alkali temperature not maintained
				Rectifire voltage not maintained
Water Rinse	Clean the wire surface to remove alkali without rubbing	Alkali retained on wire surface	Life of HCL bath will reduce	Water flow not maintained
Pre Acid cleaning (HCL- I)	Clean wire surface	Wire surface not cleaned	Reduced adhesion due to improper coating resulting into reduced tyre life	HCL I concentration not maintained
				HCL I temperature not maintained
Post Acid cleaning (HCL- II)	Clean wire surface	Wire surface not cleaned	Reduced adhesion due to improper coating resulting into reduced tyre life	HCL II concentration not maintained
				HCL II temperature not maintained
Water rinse	To neuterlise wire surface to ensure chloride less than 200 ppm in activator bath	Chloride more than 200 ppm at Activator bath	Deterioration in adhesion resulting into reduced tyre life	Water flow rate not maintained
				TDS of water not maintained
				pH of water not maintained
Coating bath	Provide Cu coating of specified wt and required % of Sn coating	Desired proportion of Cu and Sn coating not maintained	Reduced adhesion resulting into reduced tyre life	CuSo4 concentration not maintained
				SnSo4 concentration not maintained
				Bath temperature not maintained
				Free acidity not maintained
Drying Oven	Dry the wire surface o before cumar coating	Wire surface is not dried completely	Retained moisture in coating resulting into poor adhesion	Drying oven temperature
Cumar coating	Apply uniform coating of cumar on wire surface	Non uniform cumar coating	Less protection of wire from moisture and oxidation resulting into loss of adhesion property of wire coatinr	Cumar concentration not maintained

4.1 Identification Of Significant Parameters Using Principle Component Analysis: Principle component analysis has been done of the entire data collected from trial with the aim of exploring the qualitative information about the distribution of samples and variables, correlation between variables, sample and variable relationship leading to the identification of significant variables contributing to the Sn% in the coating. Interpretation of various plots of principle component analysis for the response has been described as below.

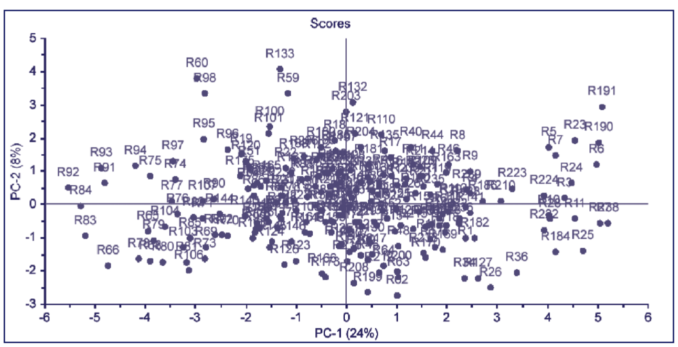
4.1.1 Correlation Loading Plot: Correlation loading plot of principle components PC1 and PC2 has been shown in Fig 4-1. The variables which fall between inner and outer circles of correlation loading circles **play significant role in**

Figure 4-1: Correlation Loading Plot



the variability of the model and hence can be considered as significant variables. However the variables which fall inside the inner circle do not

Figure 4-2: Score Plot



contribute much to the model and hence can be considered as insignificant [8].

According to the plot, following process variables fall between the inner and outer circles of correlation loading plot. These process variables may be considered significant in the PCA model

a) HCL II temperature
b) CuSo4 Concentration
c) SnSo4 Concentration
d) SnSo4 bath temperature
e) Alkali Concentration
f) HCL II concentration

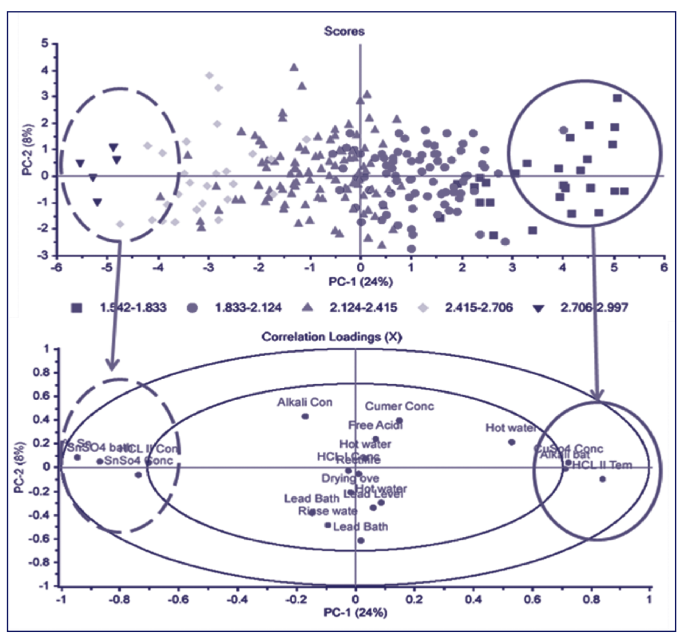
The correlation structure between the various variables can be studied using a single loading plot of principle component analysis.

It is evident from the loading plot Fig 4-1 that Sn% bears strong positive correlation with SnSo4 bath temperature since both these variables fall on the same side of a principle component axis (PC1) and also lie very close to each other. This indicates that more SnSo4 bath temperature increases the Sn% in the wire. Similarly, the SnSo4 bath temperature and HCL II concentration bear a positive correlation with Sn% as they also fall on the same side of PC1. With the same logic, we can see that SnSo4 bath temperature, SnSo4 bath concentration and HCL II temperature are positively correlated with each other which means increase in these parameters increases the Sn% in the wire [8][15].

Since HCL II temperature, CuSo4 concentration and Alkali bath temperature fall on the opposite side of PC1 they bear a negative correlation with the Sn%. This indicates that the increase in CuSo4 concentration and Alkali bath temperature reduces the Sn% on the wire. Hot water also seems to have a negative correlation with Sn%, but since it falls within the inner circle, the strength of the relationship would be low. The variables which fall along the PC2 (e.g. Lead bath temperature, Free Acidity, Cumer Concentration, etc.) would not have very weak correlation with Sn% since the PC1 and PC2 are orthogonal to each other [7].

Free acidity mostly lies along PC2 (indicating its maximum contribution towards PC2 and a very less contribution towards PC1). Also, Alkali Concentration, Alkali bath temperature & HCL II concentration have more contribution towards PC2 in comparison to PC1.

Figure 4 3: Score and Loading Plot



4.1.2 Score Plot

Score plot of all 240 samples has been plotted along PC1 and PC 2 (Fig 4-2). It can be seen that most of the samples are distributed along PC1 and variability along PC2 is much less as compared to variability along PC1.

The score plot displays the patterns (if exist), similarity and dissimilarities between the samples. No clear pattern evidenced from the score plot, however the samples which fall on the same side of the same principle component axis (PC1) of the score plot (e.g., sample nos R 191, R190, R7, R5, R 24, etc.) are considered to be the similar. Similarly, the samples which are falling on the other side of the same principle component axis (e.g. R92, R 84, R 93, R 83, etc.) are similar in nature. The samples which are falling on opposite sides of the same principle component axis will be considered as dissimilar [7] [8].

We can obtain more information by doing a joint study of scores and loading plots which is equivalent to a bi-plot [14] . A Joint study of Correlation Loading and Score plots has been done. Fig 4-3shows both the plots together.

Sn% content wise grouping has been done in the score plot of Fig 4-3. The samples with different range of Sn% are shown in different shapes. It is evident from the score plot that the Sn% varies along PC1 only. While moving from left to right in the score plot (along PC1), the %Sn value is increasing. However, no change in %Sn value is evidenced while moving from top to bottom of the plot (i.e., along PC2). On the extreme left side of the score plot, the % Sn value ranges from 1.542-1.833 and on the extreme right, the value goes up to 2.706-2.997.

4.1.3 Analysis of Score plot & Loading together

Analysis of Score plot together with Loading plot revels following information (Fig 4-3)

a) Samples falling to the extreme left of the score plot are the samples treated with high HCL II temperature, high Alkali bath temperature and high CuSo4 concentration since these variables fall on the extreme left side in the loading plot. SnSo4 concentration & CuSo4 bath temperature fall on the opposite side of these samples means these samples are treated with low SnSo4 concentration, Low SnSo4 bath temperature and low HCL II concentration. These samples will hav low Sn% since the Sn% falls on the opposite side of these samples.

b) With the above logic, samples falling to the extreme right of the score plot are the samples treated with low HCL II temperature, low CuSo4 concentration, high SnSo4 concentration & high CuSo4 bath temperature and therefore having high %Sn value. Since the %Sn is changing along PC1 only, the impact of Free acidity (which are falling mostly along PC2) on %Sn appears to be negligible.

From the analysis described above, following variables have been identified as the most potentially influencing variables for % Sn in wire.

a) HCL II temperature
b) CuSo4 Concentration
c) SnSo4 Concentration
d) SnSo4 bath temperature
e) Alkali bath temperature
f) HCL II concentration

4.2 Use Of Traditional Tools To Identify Significant Process Parameters: In order to understand the significant variables influencing the Sn% in wire coating, suitable statistical tool which can show the correlation ship between the variables is required. Scatter plot is the appropriate tool which is used to study the correlation between two variables. The scatter plot can show the correlation between the variable and response (Sn%) graphically, however, it cannot quantify the strength of correlation between them. Hence, it becomes difficult to determine how significant a variable is. This problem can be solved by determining the value of the correlation coefficient between the variable and the response (%Sn).

In order to understand the impact of each parameter on Sn%, a scatter plot of each parameter versus Sn% has been plotted followed by the determination of correlation ship between each parameter and Sn%[12][16]. In this process, 19 scatter plots have been plotted[17]. The scatter plots between variables have been shown in Fig 4-4. The correlation coefficient between each variable and %Sn has been obtained[17]. The results are summarized in Table 4-4.

From the scatter plots and correlation summary, seven parameters have been identified as the significant for the Sn% in wire coating. The summary of results of scatter plots and correlation coefficients has been presented in Table 4-3

From the analysis described above, following variables have been identified as the potentially influencing variables for % Sn in wire

a) HCL II temperature
b) CuSo4 Concentration
c) SnSo4 Concentration
d) SnSo4 bath temperature
e) Alkali bath temperature
f) HCL II concentration
g) Hot water rinse TDS

Among the seven variables identified above as significant, the confidence about the significance of Hot water rinse is low because its coefficient value in not very high to be considered as strong and not very low to be completely ignored. On careful examination of the scatter plot between Sn% and Hot water TDS, it has been found that some outlying samples have inflated the value of the correlation coefficient between them.

4.2.1 Comparison of Results

A comparative study of two different approaches for the identification of significant parameters has been presented in Table 4-5. The comparison has been done on various parameters like complexity of analysis, time spent for analysis, results obtained and information obtained from the analysis. .

Table 4-3: Summary of Scatter Plots & Correlation Matrix

S No	Variable 1	Variable 2	Interpretation from Scatter Plot	Interpretation from Correlation Matrix
1	Sn%	Lead bath I temperature	No correlation	Coefficient value -0.064, no correlation
2	Sn%	Lead bath II temperature	No correlation	Coefficient value 0.081, no correlation
3	Sn%	Lead level	No correlation	Coefficient value -0.037, no correlation
4	Sn%	Alkali bath temperature	High negative correlation	Coefficient value -0.661, high negative correlation
5	Sn%	Alkali concentration	Weak positive correlation	Coefficient value 0.16, weak positive correlation
6	Sn%	Rectifire voltage	No correlation	Coefficient value close to 0, no correlation
7	Sn%	HCL I concentration	No correlation	Coefficient value 0.028, no correlation
8	Sn%	HCL II concentration	High positive correlation	Coefficient value 0.618, high positive correlation
9	Sn%	HCL II temperature	High negative correlation	Coefficient value -0.799, high negative correlation
10	Sn%	Rinse water pH	No correlation	Coefficient value 0.061, no correlation
11	Sn%	CuSo4 concentration	High negative correlation	Coefficient value -0.648, high negative correlation
12	Sn%	SnSo4 concentration	Strong positive correlation	Coefficient value 0.654, high positive correlation
13	Sn%	SnSo4 bath temperature	High positive correlation	Coefficient value 0.888, strong positive correlation
14	Sn%	Free acidity	No correlation	Coefficient value -0.029, no correlation
15	Sn%	Hot water rinse temperature	No correlation	Coefficient value -0.033, no correlation
16	Sn%	Hot water rinse pH	Weak negative correlation	Coefficient value -0.082, no correlation
17	Sn%	Hot water rinse TDS	Moderate negative correlaction	Coefficient value -0.412, moderate negative correlation
18	Sn%	Drying oven temperature	No correlation	Coefficient value 0.006, no correlation
19	Sn%	Cumar concentration	No correlation	Coefficient value -0.071, no correlation

Figure 4-4: Scatter Plots

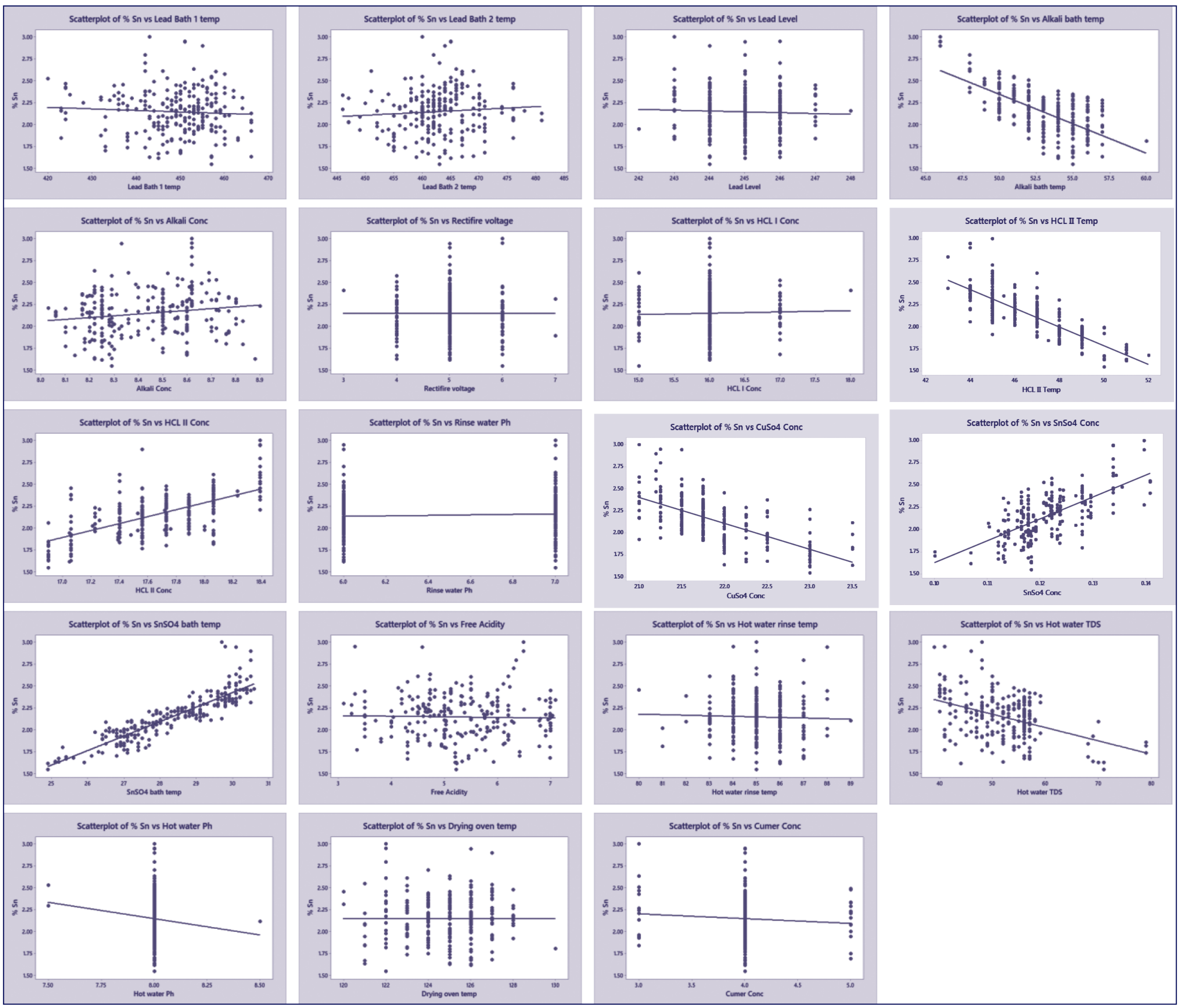


Table 4-5: Comaprison between two approaches

S No	Parameter	Multivariate Tools	Traditional Tools
1	Compexity of analysis	Low, since only score and ploading plots have to be interpreted	High, since many scatter plots and correlation coefficient have to be interpreted
2	Time spent for the analysis	Less, since only single loading plot had to be interpreted in order to arrive on a list of significant parameters	High, since 19 scatter plots and 19 correlation coefficients had to be interpreted in order to arrive on a list of significant variables
3	Results obtained	Six parameters have been identified as significant.	Seven parameters have been identified as significant, however confidence on one parameter is less.
4	Information obtained from analysis	Easy interpretation of correlation between variables using single loading plot. Score plot in conjugation with loading plot provided the additional information about the relationship of samples with variables.	Only information about the correlation between variables obtained, however many plots have to be interpreted for getting the information.

Table 4-4: Correlation Matrix

	% Sn	Lead Bath 1 temp	Lead Bath 2 temp	Lead Level	Alkali bath temp	Alkali Conc	Rectifier voltage	HCL I Conc	HCL II Temp	HCL II Conc	Rinse water Ph	CuSo4 Conc	SnSO4 bath temp	SnSo4 Conc	Free Acidity	Hot water rinse temp	Hot water TDS	Hot water Ph	Drying oven temp	Cumer Conc
% Sn		-0.064	0.081	-0.037	-0.661	0.16	0	0.028	-0.799	0.618	0.061	-0.648	0.888	0.654	-0.029	-0.033	-0.412	-0.082	0.006	-0.071
Lead Bath 1 temp			0.168	0.108	0.002	-0.146	0.056	-0.106	0.05	0.048	0.026	-0.065	-0.058	-0.048	-0.154	-0.029	-0.035	0.04	0.086	-0.031
Lead Bath 2 temp				0.031	-0.034	-0.07	0.027	-0.066	-0.108	0.063	0.068	-0.069	0.156	0.118	0.204	0.07	-0.125	0.065	0.057	-0.087
Lead Level					0.01	-0.059	0.001	0.087	0.034	-0.088	0.147	0.017	-0.033	-0.032	-0.05	-0.043	0.073	0.033	-0.027	0.051
Alkali bath temp						-0.0123	0.021	-0.064	0.514	-0.47	-0.023	0.44	-0.503	-0.505	0.176	0.002	0.253	0.059	0.019	0.125
Alkali Conc							0.042	-0.208	-0.136	0.009	-0.013	-0.135	0.124	0.119	0.025	0.002	0.003	-0.075	-0.032	0.037
Rectifier voltage								-0.11	0.044	0.017	-0.034	0.029	0.005	0.057	0.003	-0.072	0.044	0.177	-0.01	0.037
HCL I Conc									-0.035	-0.011	-0.045	-0.014	0.029	0.01	-0.068	-0.024	-0.008	0.002	0.056	0.024
HCL II Temp										-0.5	-0.009	0.596	-0.76	-0.53	0.059	0.051	0.0346	0.07	0.022	0.032
HCL II Conc											-0.048	-0.419	0.523	0.403	-0.026	-0.033	-0.452	-0.117	-0.074	-0.047
Rinse water Ph												-0.077	0.108	0.097	-0.102	0.019	-0.116	0.112	0.122	-0.132
CuSo4 Conc													-0.583	-0.457	-0.065	0.014	0.253	-0.008	-0.029	0.168
SnSO4 bath temp														0.551	0.017	0.002	-0.344	-0.073	0.044	-0.065
SnSo4 Conc															-0.071	-0.056	-0.396	0.002	0.035	-0.126
Free Acidity																0.018	0.142	-0.008	0.029	0.02
Hot water rinse temp																	0.009	-0.081	0.022	0.043
Hot water TDS																		-0.043	-0.056	0.107
Hot water Ph																			-0.111	0.001
Drying oven temp																				0.02

5 CONCLUSION

Out of the 19 parameters identified as potential parameters, a list of significant parameters have been obtained using multivariate analysis approach and traditional statistical tool approach. Out of the two approaches, multivariate analysis tools using principle component analysis have proven a better approach due to following reasons

a) Less complexity in analysis of the results since only a single loading plot could condense the information of the correlation structure between all 19 variables with Sn%. The same information required 19 scatter plots along with determination of the same number of correlation coefficients. .

b) The results accuracy is better in principle component analysis because the loading plot showed six variables as significant, however the scatter plots and correlation coefficient study resulted in one additional parameter as significant which on further investigation, turned out to be insignificant.

c) Apart from the correlation structure, principle component analysis provided additional information from the joint analysis of loading and scatter plot; no such additional information could be obtained from the analysis of scatter plot and correlation coefficient.

Future scope exist in the optimization of Sn% in wire using the parameters identified in current paper. Techniques like design of experiments using response surface methodology [18] can be adopted for deriving a model to predict and optimize Sn% in wire coating.

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