PRAJÑĀ-Journal of Pure and Applied Sciences, Vol. 19: 90 - 92 (2011)
ISSN 0975 - 2595

A CASE STUDY OF HYBRID MICROCIRCUIT ASSEMBLY PROCESS USING TAGUCHI DESIGN METHOD AND RESPONSE SURFACE METHOD

D.P. Raykundaliya* and A. Shanubhogue

P. G .Department of Statistics, Sardar Patel University, Vallabh Vidyangar – 388 120, Gujarat, India

ABSTRACT

In this paper we investigate the choice of best combination of factors for 3^7 X 2^1 mixed factorial design in 18 runs through Taguchi Design Method and Response Surface Method (RSM). Further we show that Response Surface Method predicts better optimal response as compared to optimal response obtained through Taguchi Design Method. The comparison of methods is done with the help of a case study on Hybrid Microcircuit Assembly Process conducted by Taguchi et al [5]. We do analysis using MINITAB, for the methods.

Key worlds : *shear strength; Taguchi design method; signal-to-noise ratio; response surface method; choice of the best factors combination; hybrid microcircuit; ANOVA*

INTRODUCTION

There are mainly two types of circuits used in electronic devices, namely, digital circuit and analogue circuit. The Hybrid Microcircuit is hybrid structure of one of the types of circuit. The steps required in the production of hybrid microcircuit are (1) screen (2) profile (3) atmosphere (4) gas flow rate (5) belt speed (6) drying temperature. For detail refer Condra [2]. The experiment was conducted by Taguchi et al [5] for production of hybrid microcircuit process in which they measured the shear strength of circuit. The shear strength, in engineering is a term used to describe the strength of a material or component against the type of yield or structural failure where the material or component fails in shear. A shear load is a force that tends to produce a sliding failure on a material along a plane that is parallel to the direction of the force.

Our objective in this paper is to investigate choice of the best factors combination to increase the shear strength of hybrid microcircuit. In Section 2, we discuss the principle of design of experiment and the data collected through experiment, which are given in Condra [2]. In Section 3, we discuss the results of analysis of shear strength data of hybrid microcircuit through Taguchi Design Method and Response Surface Method. We also discuss conclusions of comparative study of both designs and provide advantages of Response Surface Method over Taguchi Design Method.

THE DESIGN OF EXPERIMENT FOR THE SHEAR STRENGTH OF HYBRID MICROCIRCUIT

To use statistical approach in designing and analyzing an experiment, it is necessary to follow the basic guideline for conducting the experiment. The basic steps of guideline of design of experiments are:

(i) Recognition of problem and statement of the problem:

Here our approach is to investigate choice of best combination of factors as a result optimum value of shear strength of hybrid microcircuit.

(ii) Choice of factors, levels and ranges:

Brainstorming with experienced engineers and feasible operating ranges of machines and materials help to decide the experimental factors.

(iii) Choice of experimental design:

The study conducted for eight factors in 18 runs. The seven factors at three levels and one factor at two levels. The descriptions of these factors are given in Table 1 following Condra [2]. In statistical language our objective is to study main effects and interaction effects in this mixed factorial experiment. To conduct such an experiment one can use both $L_{18,}$ orthogonal array given by Taguchi or one can generate it using Fractional Factorial Design (Montgomery [4]; Taguchi et al [5]).

Table 1: Description of Factors and Levels for Hybrid Component Attachment Experiment

Description	Factor (variable)	Level 1	Level2	Level 3
Screen	A (x_1)	80 mesh, 0.0037 in. wire diameter, 0.003 in. emulsions	80 mesh, 0.0020 in. wire diameter, 0.002 in. emulsions	-
Profile (°C)	B(x_2)	150-200-250-300-350-350-290-240	150-200-250-300-370-370-290-240	150-200-250-300-390-390-290-240
Atmosphere	C(x_3)	100% nitrogen	50% nitrogen – 50% hydrogen	100% hydrogen
Gas Flow Rate	D (x_4)	40 cfh	60 cfh	80 cfh
Empty	E(x_5)	Dummy Variable		
Belt Speed	F(x_6)	4.5 in./min	5.5 in./min	6.0 in./min
Drying temperature	G (x_7)	Room Temperature	50°C	90°C
Empty	H (x_8)	Dummy Variable		

To analyze the data through Taguchi Design Method we require minimum two replications. Here we have three replications to measure shear strength of each factor combination. For detail regarding Taguchi Design Method and Fractional Factorial experiment readers may refer Taguchi et al [5] and Montgomery [4].

(iv) Performing the experiment and collection of data:

As the experiments are conducted in laboratory or like laboratory environment, the experimenter should first create the same environment which is actual environment prevailing while producing in a factory. The collected data on shear strength through L_{18} experiment is given in Table 2.

(v) Statistical Analysis of Data

(vi) Conclusions and recommendation

Step (v) and (vi) are discussed in details in the section of statistical analysis for Taguchi Design Method and Response Surface Method.

*Corresponding author: dp_raykundaliya@spuvvn.edu

Table 2: Experimental Design and observed Shear Strength

Run No.	A	B	C	D	E	F	G	H	Strength		
									Replication 1	Replication 1	Replication 1
1	1	1	1	1	1	1	1	1	1.65	0.01	0.45
2	1	1	2	2	2	2	2	2	0.25	0.65	0.75
3	1	1	3	3	3	3	3	3	0.01	0.25	0.25
4	1	2	1	1	2	2	3	3	0.20	0.25	0.30
5	1	2	2	2	3	3	1	1	0.60	0.35	0.40
6	1	2	3	3	1	1	2	2	2.55	2.90	2.90
7	1	3	1	2	1	3	2	3	1.40	0.65	0.40
8	1	3	2	3	2	1	3	1	2.95	2.85	3.45
9	1	3	3	1	3	2	1	2	1.95	1.95	1.30
10	2	1	1	3	3	2	2	1	0.40	0.50	0.01
11	2	1	2	1	1	3	3	2	0.01	0.01	0.25
12	2	1	3	2	2	1	1	3	0.85	1.05	1.60
13	2	2	1	2	3	1	3	2	2.50	3.15	2.75
14	2	2	2	3	1	2	1	3	2.70	2.80	1.25
15	2	2	3	1	2	3	2	1	0.01	0.20	0.01
16	2	3	1	3	2	3	1	2	0.55	0.55	0.50
17	2	3	2	1	3	1	2	3	1.35	0.70	0.50
18	2	3	3	2	1	2	3	1	0.85	1.20	0.60

STATISTICAL ANALYSIS FOR TAGUCHI DESIGN METHOD AND RESPONSE SURFACE METHOD

(a)Taguchi Design Method:

Here we note that the shear strength of hybrid microcircuit is a "larger-the better" type of characteristic. The signal-to-noise ratios are calculated through the equation for "larger-the-better" type

$$\eta_i = -10 * \log\left(\frac{1}{n}\sum_{j=1}^{n}\frac{1}{y_{ij}^2}\right) \qquad (1)$$

where y_{ij} is the j^{th} observation from the i^{th} run and n *is* number of replications of the i^{th} run. In our case we have $n=3$ and values for η_i can be calculated for shear strength of hybrid microcircuit. The resultant output obtained by analyzing data in Table 2 by considering only main effects A, B, C, D, F and G, using MINITAB software, is given in Table 3. Here again, it is to be noted that Taguchi Design is analyzed for main effects for all factors except E and H suggested by engineers. The reason is E and H are two dummy factors added to perform Taguchi Design Method using L_{18}.

Table 3: Response Value Table for Signal-to-Noise Ratio

Level	Factor					
	A	B	C	D	F	G
1	-8.9704	-25.2888	-14.0590	-20.5409	-1.7999	-6.3864
2	-12.0218	-5.8914	-7.1023	-2.2437	-8.0832	-13.5258
3	--	-0.3080	-10.3269	-8.7036	-21.6050	-11.5760

In Taguchi Design Method the level of factor is considered for optimum response is based on the maximum value of signal-to-ratio among the levels of each factor (Dharmadhikari et al [3]). The resultant recommended level of factors for the production of hybrid microcircuit having optimum shear strength is given in Table 4.

Table 4: Recommended Levels of Factors for the Production Hybrid Microcircuit

	Factor					
	A	**B**	**C**	**D**	**F**	**G**
Level	1	3	2	2	1	1

The predicted shear strength of hybrid microcircuit for recommended choice of factor combinations can be obtained by the optimum noise-to-signal ratio as a function of y . The optimum value of noise-to-signal ratio for the factor combination recommended is 25.67 and the corresponding optimum shear strength of hybrid microcircuit is 2.44.

(b) Response Surface Method:

Response Surface Methodology (RSM), is a collection of mathematical and statistical techniques those are useful for modelling and analysing response of interest as a function of several variables (factors) and objective is to optimize this response (Montgomery [4]). In RSM problems, the form of the relation is unknown. Hence, the first step is to find approximate functional relationship between y and set of independent variables $\underline{x}$. The statistical form of RSM is

$$Y = f(\underline{x}) + \varepsilon \qquad (2)$$

where ε represents the noise or error observed in the response y. Our objective is to investigate the best choice of factor combinations which give optimum value of response on the surface of response. The first step of RSM is to investigate the distribution of average shear strength of hybrid microcircuit (y). The distribution of average shear strength of hybrid microcircuit is found to be Lognormal from its Normal Probability Plot (Figure 1). Further the p-value of Anderson-Darling test of fitting of normal distribution for y, is 0.637 (> 0.05) which indicates, the Lognormal distribution fits well to shear strength of hybrid microcircuit.

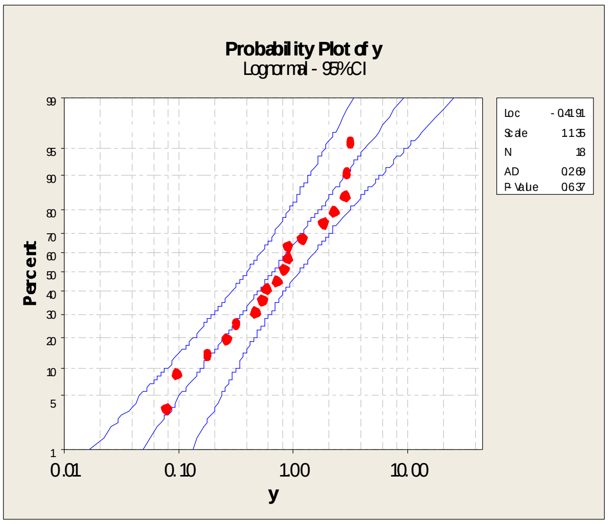

Figure 1: Normal Probability Plot of Shear Strength of Hybrid Microcircuit

The maximum likelihood estimators of parameters of the Lognormal distribution and its properties have been studied (Aitchison and Brown [1]). A positive continuous random variable X is said to follow the Lognormal distribution if the variable $\log_e X$ has Normal distribution with mean μ and variance σ^2. Before fitting RSM to the data in Table 2 for identifying which effect to be included in the model, we draw main effect plots for all factors given in Figure 2.

The analysis of the log transformed average shear strength of hybrid microcircuit is carried out through MINITAB by considering main effects A, B, C, D, F and G. The reason is that the experiment is carried out for the first time and the analysis is done for un-coded observations in MINITAB. The resultant output is given in Table 5 (Estimates of effects) and Table 6 (Analysis of Variance Table).

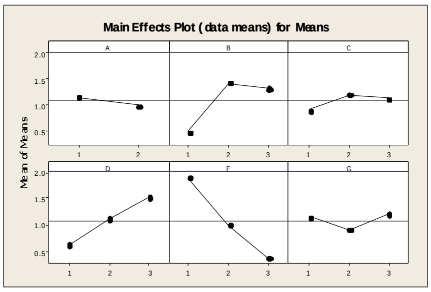

Figure 2: Main Effect Plots for log of average Shear Strength of Hybrid Microcircuit

Table 5: Estimated Regression Coefficients for log (average shear strength of hybrid microcircuit)

Term	Coefficient	SE coefficient	T	P-value
Constant	0.384205	0.8475	0.453	0.659
A	-0.30275	0.2680	-1.130	0.283
B	0.560566	0.1641	3.416	0.006**
C	-0.00402	0.1641	-0.024	0.981
D	0.478207	0.1641	2.914	0.014**
F	-0.93677	0.1641	-5.708	0.000**
G	-0.27256	0.1641	-1.661	0.125

S=0.5685 R-sq = 83.8% R-Sq (Adj) = 74.9% * p-value (<0.05) ** p-value (<0.01)

Table 6: Analysis of Variance of ln (Average Shear Strength of Hybrid Microcircuit)

Source	DF	Adj. SS	Adj. MS	F	P-value
Regression	6	18.3496	3.05827	9.46	0.001**
Linear	5	18.3496	3.05827	9.46	0.001**
Residual Error	11	3.5551	0.32319		
Total	17	21.9047			

** p-value (<0.01)

The R-Square value given in Table 5 indicates that 83.8% of total variation in ln(y) is explained by the fitted model. Further from ANOVA given in Table 6 we observe that both linearity assumptions and fitted regression model for main effects are highly significant. It is observed that only main effects B, D and F are significant at 1% level of significance. Thus the fitted Response Surface Model for ln (y) is :

$$\ln(y) = 0.384205 - 0.30275x_1 + 0.560566x_2 - 0.00402x_3 + 0.478207x_4 - 0.93677x_6 - 0.27256x_7 \quad (3)$$

From the study of main effect plots of average shear strength of hybrid microcircuits for selected factors (Figure 3), the recommended best combination of level of factors is given in Table 7.

Table 7: Recommended Levels of Factors for the Production of Hybrid Microcircuit through RSM

	Factor					
	A	**B**	**C**	**D**	**F**	**G**
Level	1	2	1	3	1	1

The optimum value of ln (y) for above recommended levels of factor for the production of hybrid microcircuit using equation (3) is 1.424 and corresponding average shear strength of hybrid microcircuit is 4.14. It is interesting to note that RSM gives 69.6% more optimal value as compared to Taguchi Design Method.

Advantages of using Response Surface Methodology:

1. It is a Statistical/Mathematical modelling technique.
2. It can help to find optimum value for response beyond or within the range of level of factors suggested by the engineers.
3. It will help to identify the future direction of optimum response.
4. It can also identify the interaction or curvature effects beyond the imagination of engineers.
5. It can also investigate whether the effects are statistically significant. As a result on can construct 95% confidence interval for main effects which can help to identify future range of level of factors.

Disadvantages of Taguchi Design Method:

1. It is purely a philosophy, no Mathematics involved.
2. It gives only the optimum value at any of the levels specified by experimenter.
3. It will not give the future direction of optimum response in experiments. Further, to know the future direction of optimum value we require conducting a new experiment.

REFERENCES:

[1] Atchinson, J. and Brown, J.A.C. (1957). The Lognormal Distribution. Cambridge University Press, Cambridge.

[2] Condra, L.W. (2001). Reliability Improvement with Design of Experiments, Edition II, Marcel Deker, 47-61

[3] Dharmadhikar, D.A., Kharshikar, V.A., Ratnaparkhi, M.V. and Prasad, K. (2000). "Analyzing the Censored Life Data arising in Fractional Factorial Designs: Spin-on-filter Case Study". Quality Engineering, 13(1), 65-72.

[4] Montgomery, D.C. (2004). Design and Analysis of Experiments. Edition V, John Wiley and Sons (Asia).

[5] Taguchi, G. and Konish, S. (1987). Orthogonal Arrays and Linear Graphs. American Supplier Institute, Dearborn, MI.

ACKNOWLEDGMENT:

This research is funded by University Grant Commission (UGC) for Minor Research Project (F.37-549/2009(SR)). The First author wishes to thank Prof. D.K.Ghosh for helpful discussion during his visit in Department and Dr.Jyoti M.Divecha for helpful discussion.