EFFECT OF ENTRY MATERIAL ON SURFACE ROUGHNESS IN DRILLING PROCESS OF PRINTED CIRCUIT BOARD USING TAGUCHI DESIGN METHOD

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ABSTRACT

In this work, different entry materials were micro drilled for printed circuit board. The optimization of different parameters is done by using Taguchi Approach. In this experiment L_{16} orthogonal array is used with three controllable factors like spindle Speed, feed and material with four levels of each to find out optimum level of parameters to minimize the surface roughness. The ANOVA results used to find out significant factor and percentage contribution of individual factor. From ANOVA analysis it is found that Spindle speed is most contributing factor for surface roughness with contribution of 67.66%. Confirmation tests have been carried out to predict the optimal setting of process parameters to validate the proposed method

Keyword: - *Drilling[1], Taguchi method[2], Surface roughness[3], ANOVA[4], Minitab 16[5].*

1. INTRODUCTION

A Printed Circuit Board (PCB) mechanically supports and electrically connects with the electronic components using conductive tracks, pads and other features engraved from copper sheets laminated onto a non-conductive substrate. PCBs may be single sided (one copper layer), double sided (two copper layers) or Multi-layer (outer and inner layers). Multi-layer PCBs allow for much higher component density. Advanced PCBs might contain components such as capacitors, resistors or active devices embedded within the substrate. Glass epoxy is the primary insulating substrate upon which the large majority inelastic PCBs are produced. A thin layer of copper foil is laminated to one or both sides of panel. Circuitry interconnections are engraved into copper layers to fabricate printed circuit boards. Complex circuits are produced in multiple layers. Printed circuit boards are used in all the simplest electronic products. Alternatives to PCBs comprise wire wrap and point-to-point construction. PCBs demand the supplementary design effort to lay out the circuit, but manufacturing and assembly can be automated. Manufacturing circuits with PCBs is economical and rapid than with the other wiring methods as components are mounted and wired with one single part. Furthermore, operator wiring errors are eliminated. [23]

Drilling provides the holes for the electronic components to be placed on PCB surfaces. Burrs are thereby created on both the entrance and exit surfaces of a PCB. In the drilling process, burrs are produced on both the entrance and exit surfaces of the workpiece. However, the formation mechanisms are different. Entrance burrs are formed via plastic flow, while exit burrs are formed as the material extends off the exit surface of the workpiece. Generally, exit burrs are larger than entrance burrs, and are undesirable because they cause most burr-related problems, such as interference with the assembly of parts, which leads to jamming and misalignment, reduces the fatigue life of the parts, and acts as a crack initiation point and safety hazard. Deburring is often required, but in the case of micro-drilling, manual removal of burrs is not practical, and sometimes even impossible. [16]

The printed circuit board (PCB) industry is developing rapidly with the expanding demand of mobile phones, notebook computers, liquid crystal displays and other digital products in recent years. One essential step to manufacture PCBs is drilling holes through to electrically connect two or more copper layers. However, PCBs are not easy to be machined due to the adhesive properties of copper layers, as well as the anisotropy and highly abrasive nature of the fibers in the resin. This makes micro drills wear dramatically after a relatively short period. The short tool life and more frequent replacing tool have become the obstacle of high efficiency machining in the PCB industry. Coating thin hard films on PCB micro drills may be one challenging way to deal this problem, as hard coatings could effectively protect cutting edges from wear during cutting process thus prolong the working life of cutting tools. [14]

Printed circuit boards (PCBs) are high-priority components in almost every electronic product. Since the electronic circuit path is printed on nonconductive sheet material, PCBs facilitate miniaturization of electronic devices with high levels of integration. PCBs contain a number of holes and slots connecting the circuit path, and micro-end-mills with diameters of several hundred micrometers are used to machine the slots. In accordance with recent remarkable developments in the PCB industry, several approaches have been studied to improve machinability and productivity. [13]

Drilling is a particularly complex machining process, and it becomes much more complex when the workpiece is PCB. PCB is composite materials with anisotropy. Tool trends to wear and break. The precision hole location, the appearance of entry and exit burrs, smear of resin on the sides of holes, delamination and so on may influence quality of boards. Only a small one of these defects may cause great losses. In order to prevail over these complications, both the drilling process and PCB structure design have been researched by many scholars. But the study on the drilling processes of PCB are not systematic. The present review article delivers the details about tool materials and geometrics, cutting force, cutting temperature, radial run-out and damages arise during drilling processes. And as a conclusion, some of these critical issues are proposed to meet the challenges in analysis and optimization for PCB drilling. [9]

2. LITERATURE REVIEW

Hae-Sung Yoon et al. (2013), studied control of machining parameters for energy and cost savings in micro-scale drilling of PCBs. The aim of this investigation is to develop new models and methodologies to manage the energy consumption and production costs in the micro-drilling process for printed circuit board manufacturing. In microscale machining, the energy engrossed in material removal is negligible compared to the energy consumed by the machine modules. A set of experiments was performed to gather information on the energy consumption of the machine modules and their tool life. The results clearly states the energy consumption and manufacturing cost trends in terms of the process parameters. Faster machining can reduce the energy consumption, but increases the cost. Considering only the cost facet of the drilling process, 35% of the manufacturing cost can be saved. Using the proposed model, operators can select the appropriate process parameters by considering the conflict between minimum energy and minimum cost criteria, as well as local conditions. [12]

Binayak Bhandari et al. (2014), studied development of a micro-drilling burr-control chart for PCB drilling. In this investigation a drilling burr-control chart (DBCC), based on experimental results, is a tool for the prediction and control of drilling burrs for a huge radius of drilling parameters. A micro-drilling burr-control chart (M-DBCC) was generated for excellent double-sided copper-clad laminated (CCL) printed circuit board (PCB) with laminated fiber-reinforced plastic (FRP) substrate. This chart will help in choosing of favorable drilling parameters for predicting and accomplishing preferred types of burrs. Burr categorization was carried out according to the burr geometric features, burr formation mechanisms, burr height, and drill bit breakage while drilling. The design of experiment (DOE) technique based on the Taguchi method was used to find the most remarkable drilling parameter influencing burr height. The results showed that the drill diameter makes a statistically significant contribution to burr-height variation. [16]

Reddy Sreenivasulu et al. (2016), investigated prediction Of Burr Size in Drilling Operation of Al 2014 Alloy Using Taguchi Design Method. This analysis presents the result of cutting parameters like cutting speed, feed rate, drill diameter, point angle and clearance angle on the burr size of Al 2014 alloy during drilling on CNC vertical machining center. A set of investigations based on Taguchi method has been used to obtain the data. An orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are utilized to analyse machining characteristics using HSS twist drill bits with variable tool geometry and conserve constant helix angle of 450 . Confirmation tests have been carried out to predict the optimal setting of process parameters to validate the proposed method and obtained the values 0.232 mm and 0.173 mm for burr height and thickness respectively. [17]

Khaled Giasin et al. (2016), studied chip formation, Hole size, Circularity and Delamination during Drilling Operation of GLARE using ANOVA. The focus of this work is to enlarge the knowledge of machining fibre metal laminates along with the assessment of twist drilling operations in order to improve workpiece grade. The current work presents an experimental study to examine the outcome of drilling parameters (spindle speed and feed rate) on hole quality in two grades of GLARE (2B & 3). The analysis comprises inspecting the hole size, circularity error, entry and exit burrs, chip formations and damage described at the macro level (delamination area) using computerized tomography CT scan, and at the micro level using scanning electron microscopy (SEM). In addition, the results are statistically examined using analysis of variance (ANOVA) to discover the contribution of cutting parameters on investigated hole quality parameters. [18]

A. Dogrusadik et al. (2017), studied comparative assessment of support plates' influences on delamination damage in micro-drilling of CFRP laminates. In this experimental work, drilling induced delamination damage which occurs during micro-drilling of CFRP laminates was investigated experimentally under variable cutting speeds and feed rates. Using support plates which are placed front and rear sides of the CFRP laminate is one of the methods which limits the delamination damage. Two different setups of support plates were used in the experiments. In the initial setup, the entry board was aluminum plate and the backing board was phenolic plate. In the second setup, the entry board was brass plate and the backing board was of the wooden plate. Hole images were taken from each and every CFRP laminate by utilizing a digital microscope. The first, the middle and the last three holes were inspected from the front and rear sides of the CFRP laminate. Minitab was used to evaluate the experiments outputs and response surface method was used to optimize the process parameters. It has been revealed that the delamination damage in micro-drilling differs from the delamination damage in conventional drilling of CFRP laminates. [20]

3. EXPERIMENTAL METHODOLOGY

3.1 Experimental Design

In this work drilling operation was performed on printed circuit board material. The parameters identified for investigation are Spindle speed, Feed and material. The selected process parameter and their levels are shown in Table 1. Levels of experimental parameters consist of cutting speed ranging from (400-700), Feed rate (0.11-0.14) and Material A= Copper + Backup, B= Backup + Copper + Backup, C= Aluminium + Copper + Backup, D= Bakelite + Copper + Backup.

Table -1: Control factors and their levels

Control Factors	Units	Level I	Level II	Level III	Level IV
Spindle Speed	rpm	400	500	600	700
Feed	mm/min	0.11	0.12	0.13	0.14
Material	-	A	B	C	D

3.2 Taguchi Method

Orthogonal array is one of the Taguchi tool, which takes out the quantity of test required, decreases the cost, and reduce the time of trials. The Orthogonal array L_{16} is shown in Table 2. Taguchi gives three types of quality characteristics Smaller the better, Nominal the better and Larger the better.

3.3 ANOVA Analysis

Analysis of variance (ANOVA) of the complete grade is done to show the important parameters. If the P value for a factor becomes less than 0.05 then that factor is considered as significant factor at 95% confidence level. Statistical software with an analytical tool of ANOVA is used to decide which parameter significantly influence the performance characteristics.

3.4 S/N ratio

The signal-to-noise (S/N) ratio calculates how the response varies relative to the nominal or target value under distinct noise conditions. You can select from various different S/N ratios, depending on the goal of your experiment. Taguchi introduced three types of quality characteristics Smaller is better, Nominal is better and Larger is better

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the smaller-is-better S/N ratio using base 10 log is:

$$\text{S/N Ratio} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(Y_i^2)\right] \quad \text{---------------} \ (1)$$

Where Y = responses for the given factor level combination and n = number of responses in the factor level combination.

Table -2: Taguchi L_9 Orthogonal array

Run	Factor 1 Spindle Speed (rpm)	Factor 2 Feed rate (mm/min)	Factor 3 Material
1	400	0.11	A
2	400	0.12	B
3	400	0.13	C
4	400	0.14	D
5	500	0.11	B
6	500	0.12	A
7	500	0.13	D
8	500	0.14	C
9	600	0.11	C
10	600	0.12	D
11	600	0.13	A
12	600	0.14	B
13	700	0.11	D
14	700	0.12	C
15	700	0.13	B
16	700	0.14	A

4. EXPERIMENTAL PROCEDURE

The experiments are conducted using Lenz PCB drilling machine. The photograph of experimental set up as shown in Figure 2.

Fig -2: Photograph of experimental set up

After Machining the Surface Roughness of machined component is measured using a contact type surface roughness tester. The Table 3 shows the results for Surface Roughness.

Table -3: Experimental result for Surface Roughness

Run	Factor 1 Spindle Speed (rpm)	Factor 2 Feed rate (mm/min)	Factor 3 Material	Surface Roughness (µm)
1	400	0.11	A	0.47
2	400	0.12	B	0.54
3	400	0.13	C	0.31
4	400	0.14	D	0.48
5	500	0.11	B	0.71
6	500	0.12	A	0.56
7	500	0.13	D	0.70
8	500	0.14	C	0.44
9	600	0.11	C	0.59
10	600	0.12	D	0.78
11	600	0.13	A	0.81
12	600	0.14	B	0.89
13	700	0.11	D	0.80
14	700	0.12	C	0.71
15	700	0.13	B	0.94
16	700	0.14	A	0.96

5. RESULT & DISCUSSION

The Signal to Noise (S/N) Ratio for Surface Roughness is calculated by using Smaller the better characteristic. The S/N Ratio outcome for Surface Roughness is as show in the Table 4.

Table -4: Calculated S/N ratio for Surface Roughness

Run	Factor 1 Spindle Speed (rpm)	Factor 2 Feed rate (mm/min)	Factor 3 Material	Surface Roughness (µm)
1	400	0.11	A	6.56
2	400	0.12	B	5.35
3	400	0.13	C	10.17
4	400	0.14	D	6.38
5	500	0.11	B	2.97
6	500	0.12	A	5.04
7	500	0.13	D	3.10
8	500	0.14	C	7.13
9	600	0.11	C	4.58
10	600	0.12	D	2.16
11	600	0.13	A	1.83
12	600	0.14	B	1.01

13	700	0.11	D	1.94
14	700	0.12	C	2.97
15	700	0.13	B	0.09
16	700	0.14	A	0.35

5.1 Analysis of Surface roughness

The Analysis of variance result for Surface Roughness as shown in Table 5. From the result of ANOVA for Surface Roughness the Spindle speed shows more contribution of 67.60 %, material shows 27.96 % contribution and feed rate has lowest contribution of 0.16 %. Here the residual error was found as 4.27 %.

Table -5: ANOVA for Surface Roughness

Source	DF	Seq SS	Adj MS	F	P	% Contribution
Spindle Speed	3	76.104	25.3679	31.67	0.000	67.60
Feed rate	3	0.179	0.0598	0.09	0.971	0.16
Material	3	31.487	10.4955	13.10	0.005	27.96
Residual error	6	4.806	0.8010			4.27
Total	15	112.576				100

Figure 4 shows the main effect for S/N Ratio of Surface Roughness. From figure 5 the optimum level of cutting parameters is obtained at Spindle speed of 400 rpm, feed of 0.11 mm/min and material of C (Aluminium + Copper + Backup).

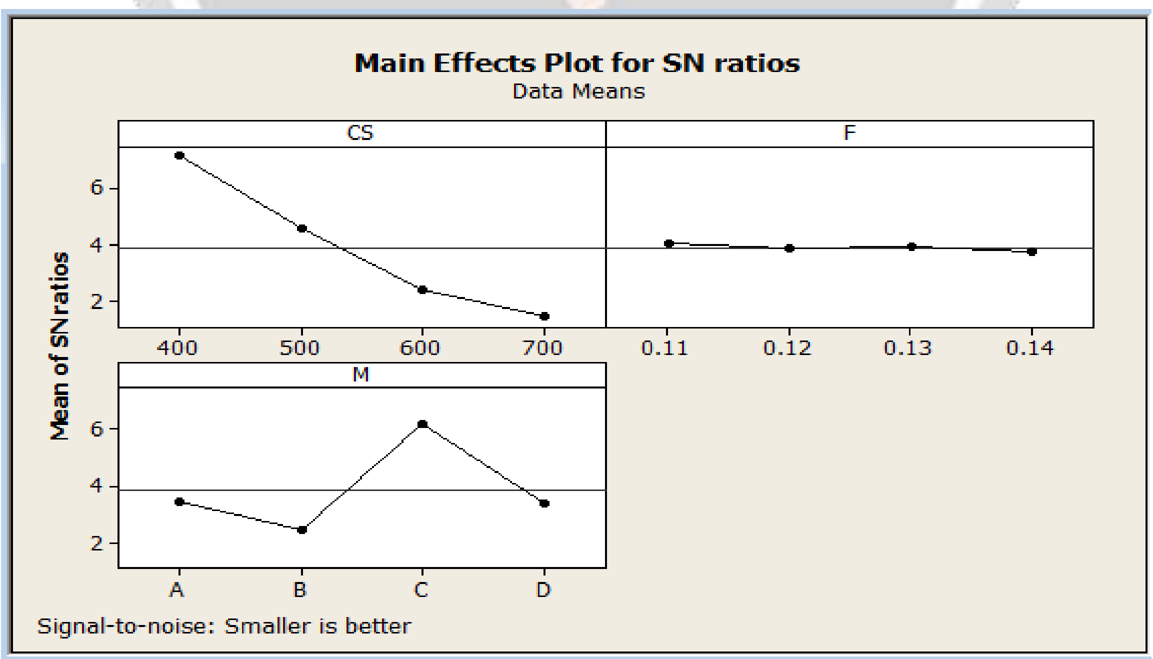

Fig -4: Main effect plot for S/N ratio of Surface roughness

From response Table 6 it is observed that that Spindle speed has the greatest influence on the S/N ratio also material has the next greatest influence followed by feed.

Table -6: Response of S/N ratio for Surface Roughness

Level	Spindle speed	Feed rate	Material
1	**7.115**	**4.014**	3.445
2	4.560	3.880	2.357
3	2.396	3.797	**6.215**
4	1.451	3.718	3.392
Delta	5.663	0.295	3.746
Rank	1	3	2

5.2 Confirmation Experiment

The confirmation experiments have been conducted at optimum levels of machining parameters and the result was found as shown in the table 7
.

Table -7: Confirmation Test

Verification Experiment No	Verification Experiment For	Experimental Value	Predicted Value
1	Minimum Surface roughness	0.28	0.2562

6. CONCLUSIONS

In this work sixteen experiments were conducted with four levels of drilling parameters. Influence of spindle speed, feed and material were investigated by using taguchi and ANOVA analysis. From analysis the following conclusions are drawn:

1. From ANOVA analysis it is found that Spindle speed is most contributing factor for surface roughness with contribution of 67.66%.
2. From ANOVA analysis it is found that Material is most contributing factor for surface roughness with contribution of 27.96%.
3. The optimum parameters level setting for surface roughness is found at Spindle speed of 400 rpm, feed of 0.11 mm/min and material of C (Aluminium + Copper + Backup).
4. Taguchi method successfully optimizes cutting parameters in Drilling machining process.

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