ANALYTICAL SIMULATION AND EXPERIMENTAL INVESTIGATION OF VARIOUS CHARACTERISTICS OF HOLE QUALITY DURING MICRO DRILLING OF PCB

Satyaprakash Sahoo
Roll No: 111ME0342
Department of Mechanical Engineering,
National Institute of Technology Rourkela
Rourkela-769008
Odisha, India

Analytical Simulation and Experimental Investigation of Various Characteristics of Hole Quality During Micro Drilling of PCB

A Thesis Submitted for Partial Fulfilment
of the Requirements for the degree of

Bachelor of Technology
in

Mechanical Engineering
by

Satyaprakash Sahoo
Roll No: 111ME0342

Under the Supervision of
Dr. Soumya Gangopadhyay.

Department of Mechanical Engineering,
National Institute of Technology Rourkela
Rourkela-769008
Odisha, India

National Institute of Technology, Rourkela

CERTIFICATE

This is to certify that the work in the thesis entitled "**Analytical Simulation and Experimental Investigation of Various Characteristics of Hole Quality During Micro Drilling of PCB**" by **Satyaprakash Sahoo**, has been conducted under my supervision required for partial fulfillment of the requirements for the degree of Bachelor of Technology in Mechanical Engineering during session 2014-2015 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

Dr. Soumya Gangopadhyay
(Supervisor)
Assistant Professor
Department of Mechanical Engineering,
National Institute of Technology, Rourkela

ACKNOWLEDGEMENT

I would like to acknowledge the support of my supervisor, **Dr. Soumya Gangopadhyay** for his encouragement, advice, mentoring and research support throughout my studies. His advice was highly essential for the completion of this project. His words of wisdom during the project were a source of inspiration.

I am very thankful to **Ms. Aruna Thakur, Research Scholar** of Department of Mechanical engineering who helped me constantly throughout the project duration.

I would also like to thank **Mr. Kumar**, CNC operator, Central Workshop, for assistance in completing experiments.

ABSTRACT

Achievement of good surface quality remains a concern during micro drilling of printed circuit board (PCB). Although a great deal of work is reported on micro drilling of PCB, information on effect of drilling parameters like feed on different characteristics of hole quality is relatively scarce. Although stresses during micro drilling of PCBs are critical issues, their correlation with hole quality is yet to be reported. The current work utilizes finite element analysis based simulation of deformation and stresses to explain the various parameters of hole quality such as diameter, delamination factor and burr thickness. Effect of feed on these parameters has also been established. Results indicated that stresses play a vital role in influencing hole qualities of PCB. Increase in feed rate resulted in reduction in hole diameter, whereas delamination factor and mean burr thickness increased with feed. The study is, therefore, expected to be of help in proper selection of feed in order to achieve acceptable hole quality after micro drilling of PCB.

CONTENTS

List of figures

List of tables

CHAPTER 1

INTRODUCTION

Micro machining involves the production of miniaturized products which are now widely used in various production sectors like automobile, medical, electronics and other precision industries. Development of micro machining has led to wide applications of micro electro mechanical systems (MEMS). Thus, application of products from micro machining has increased in the last decade and it will see more demand in the coming years.

Mechanical micro machining can be divided into several categories like micro turning, micro milling micro drilling and others as in the case of conventional machining depending on the type of material removal. There are several unique challenges related to the process mechanics encountered during micro machining processes making them distinct from the conventional machining domain. Minimum chip thickness is one of them i.e. the depth of cut should be greater than critical chip thickness otherwise chips may not be formed in micro milling [1]. Micro machining can be analyzed in the micro structural level. So the mechanism has significant difference with the macro machining process. The micro structure affects various parameters like specific cutting force, dynamic instability and surface finish, since the work material no longer behaves like a homogenous material [2]. The tool dimension in micro machining has same order of magnitude with that of size of various grains. The grain body and the grain boundary are shown in Fig. 1. This difference is highly pronounced in metallic alloys [3, 4]. Vibration during machining has significant effect on the product qualities as there is distortion in the micro level due to the variations due to vibration. Formation of burr is one of the major challenges as it deteriorates the product quality which are the result of poor backing and entry material, high feed, speed and worn drill bit [5].

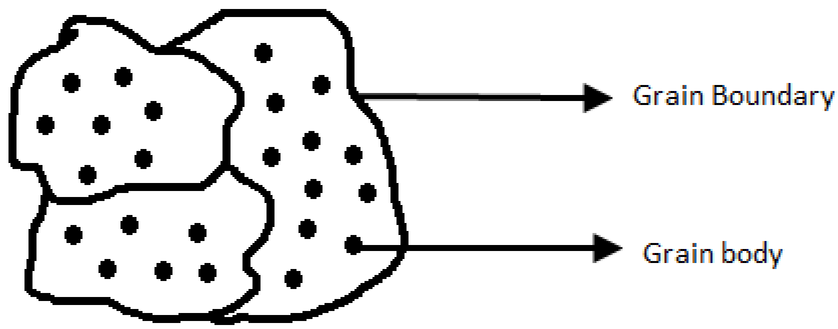


Fig. 1: Schematic representation of general microstructure of material

A great deal of research interest is growing in the field of micro machining with a challenge to maintain precision, perfect geometry and good surface finish. Compared to mechanical micro drilling, other hole making processes like laser, plasma, electron and ion beam machining have high set up time, high initial investment and low material removal rate (MRR), thus are not so economical for small batch production. Therefore, micro-drilling is one of the preferred options as a hole making process. Micro-drilling involves fabrication of holes of very small diameter (micro-holes) which is typically less than 0.5 mm [6]. Expansion of the electronics industry is creating scopes for micro drilling of printed circuit boards (PCB). Moreover, micro-drilling has wide application in the field of automobile, aerospace, computer, electronics equipment, medical instrumentation and other precision product industries.

A printed circuit board is one of the most basic components in the electronics industry. Its main components are glass fiber reinforced plastic and copper foil which are stacked alternatively to get the required structure as shown in Fig. 2. The composite acts as a layer of dielectric between the conductive copper layers. Moreover, it provides strength and rigidity. The copper foil is laminated on the GFRP (may be either on one or on both sides) through heating action and adhesives. Their features are designed so as to satisfy the mechanical and electrical requirements of electronic circuits. It is preferred to other materials due to its low cost and light weight, high rigidity and reliability.

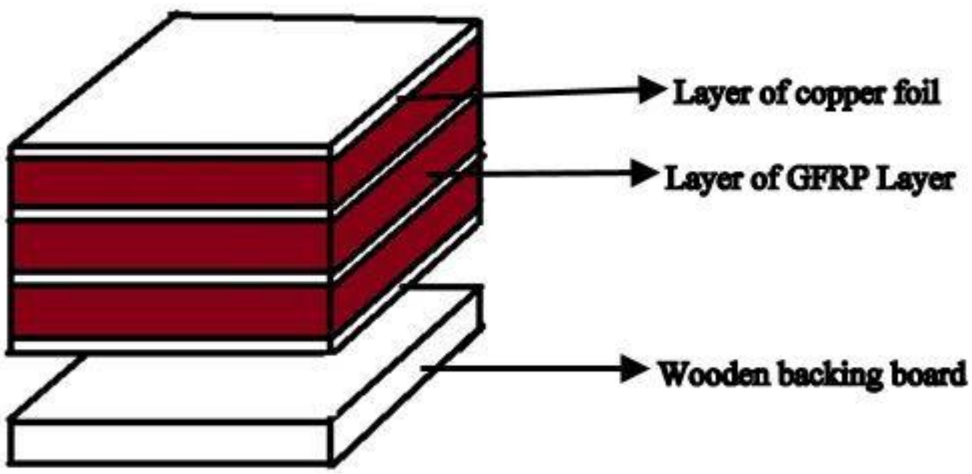


Fig.2: Different layers of PCB

Various types of tools are used for micro drilling of different materials. Some of them are high speed steel (HSS), carbide tools like tungsten carbide and cemented carbide tool. HSS tools can withstand more cutting forces than carbide tool and are cheaper. Tool life for HSS tool is higher at intermittent cutting applications. Carbide tools are extensively used due to their wide range of cutting speed.

CHAPTER 2

LITERATURE REVIEW

Various investigations were carried out in the field of micro-drilling with different work-piece and tool materials. The effects of different parameters like drill bit temperature[4], drill diameter[5,7],spindle speed & feed[2] on the hole qualities parameterized by burr height, hole wall roughness were estimated. Nakagawa et al. studied the influence of workload, based on the measured torque during drilling, on drill temperature and surface roughness of the drilled hole wall was evaluated. Drill diameter also influences hole wall roughness. Better roughness is achieved with larger diameters in a certain range [4, 7]. Bhandari et al. established the inter relation between drill diameter and burr height. Variation of burr height with spindle speed, feed and diameter of drill was found [5]. Zheng et al. investigated to optimize the drilling parameters for decreasing burr size and thrust force. Burrs are formed during the entry and exit of the drill bit. Enter burr is formed mainly due to burr bending and exit burrs are formed both due to burr bending and burr break up [8]. Edoardo Capello found absence of support during drilling to be the main reason behind delamination. A new support device was built which effectively reduced delamination [9]. Rahamathullah et al. conducted micro drilling on carbon fabric laminate composites using carbide tool of 0.32mm diameter; measured the thrust force and torque; found the diameter of the hole, delamination factor and roundness error. A power law based regression model for thrust force and torque was estimated which approximately matched the results measured from the experiment [10, 11]. Imran et al. studied surface integrity in micro-drilling. They concluded that subsurface alterations are driven by thermo-mechanical loading, causing plasticity and grain refinement by excessive shearing local to the cut surface [12].

Hinds et al. developed the finite element model of drill bit and correlated the stress in drill bit and tool life. It was confirmed that tools with less stress have longer life [13]. Yongchen et al. analyzed the dynamic stress in micro drills & drilling machine under high speed machining. A dynamic model of the system was created using Timoshenko beam element. The effects of the eccentricity, the drilling axial force, the rotational inertia, the gyroscopic moment and the spindle bearings on bending deformation of micro-drills during drilling which leads to the failure of the drill-bit were studied. Stresses on the weakest section were studied using the measured drilling axial force and torque [14]. Yoon et al. found the specific energy consumption at different parameters and optimized it [15]. Size effect in machining is defined as the nonlinear increase in specific cutting force with decrease in undeformed chip thickness into micro scale. Anand et al. predicted a mathematical model to relate specific cutting force with the ratio of undeformed chip thickness to cutting edge radius. The optimized condition to minimize the cutting forces for austenitic stainless steel was found. Feed affects the radial and thrust components of the forces significantly [16, 17].

Different types & mechanisms of wear such as abrasive, adhesive, flank & chisel edge wear were studied. A characteristic wear map of cutting conditions was constructed for the micro-drilling process by Imran et al. which helps in identifying the zones of lowest wear rate. The wear rate map provides a reference for selecting cutting parameters for objective of minimum cost and/or maximum productivity [18]. Zheng et al. studied the mechanism of the wear using a cemented tungsten carbide drill bit. Abrasive as well as adhesive wear along with the reasons of wear were analyzed. They also demonstrated two body and three body abrasive wear on the flank surface and the chisel edge of the drill bit. The smaller diameter drill bits suffer more wear [7, 19, and 20]. Imran et al. compared the tool wear in the dry and wet machining conditions. The main wear phenomena in wet conditions are abrasion, diffusion and micro chipping and those in the dry conditions are abrasion, adhesion, macro chipping and catastrophic failures [21]. Lee et al. did the modelling for cutting force for alumina green bodies with diamond grit abrasive micro-drills. They also concluded that tool life decreased linearly with feed due to abrasive wear and chip loading [22].

Wear resistance of cemented carbide micro drill can be augmented by depositing coating of suitable materials like chromium based thin film coating doped with W-C-N [23], atomic layer deposition[ALD] coating[24], a-C:H:Nx% coatings with various levels of nitrogen[25] & TiN/AlN coating[26]. Superior tribological properties in the form of less drill wear & coefficient of friction along with enhanced tool life were noted with the application of coatings [23-27]. Nam et al. using nano fluids minimum quantity lubrication showed that the forces and torques can be decreased, the number of holes can be increased in certain time and remaining chips and burrs after machining can be eliminated to enhance the quality of the holes [28].

Effects of drill bit specifications on machining were studied by several researchers. Drill bits with large helix angles, large flute to land ratio and small web thickness give excellent performance. Big helix angle, small primary face angles and small point angles should be implemented in the design of ultra-small micro drill bits [29]. Gong et al. modelled for critical speed and critical buckling loads using finite element model and found that both increase with increase in cross sectional area and helix angle of the drill bit [30].

Zheng et al. concluded that morphology of chips and hole wall surface depends on the material properties, feed rate, spindle speed and tool wear. Different types of chips are formed from different layers of PCB [31]. During machining of PCB different types of chips are formed:

aluminium chips from cover board, copper chips from copper foil and discontinuous chips from CFRP. Feed rate and speed affect the chip morphology [32].

Motivation

Quality of the hole remains one of the major challenges in micro drilling. There are several characteristics which affect the hole quality of PCB. Although there was significant work on optimization of micro drilling parameters for PCB, information on effect of feed rate on hole quality parameters is relatively scarce. Analytical simulation of stresses and their correlation with quality of holes during micro drilling of PCB has also hardly been reported been so far. Therefore, the current research has been undertaken to address some of these relevant issues in micro-drilling of PCBs.

Objectives

Keeping in view of the research gaps discussed in the preceding section, the objective of the current study is formulated as follows:

- To carry out micro drilling in PCB using solid carbide drill bit at constant spindle speed with different feeds.
- To investigate the effect of variation of feed on hole quality parameters like diameter of the drilled hole, delamination factor and burr thickness.
- To estimate the value of maximum principal stress and total deformation of the tool using force and torque data by ANSYS software.
- To correlate the simulated results with the variation of the hole quality parameters.

CHAPTER 3

MATERIALS AND METHODS

Experimental Procedure

A square shaped printed circuit board (PCB) of dimension (150*150*2 mm^3) was considered as the work piece consisting of resin impregnated glass fiber and copper clad laminate. The work piece was clamped on the CNC bed with a wooden backing board. Standard two-flute helical, uncoated, solid cemented carbide micro drill (SD26-0.30-1.80-3R1, Make: SECO) was used in all the experiments. The tool specifications and properties are provided in Table 1. Drilling of the PCB was performed in a CNC Machine (MTAB, Maxmill, Bangalore). The specification of CNC machine is shown in Table 2. Fig. 3 shows the photograph of experimental setup. Fig. 3 shows the SEM image of the drill bit before machining. Fig. 5 shows the drafted image of the drill bit with dimensions and Fig.6 shows the the 3D model in SOLIDWORKS attached with. The experiments were carried out with constant speed and three different feeds. A fresh drill bit was used for machining with each feed. The experimental conditions are mentioned in Table 3.

Fig. 3. Experimental setup of micro-drilling of PCB.

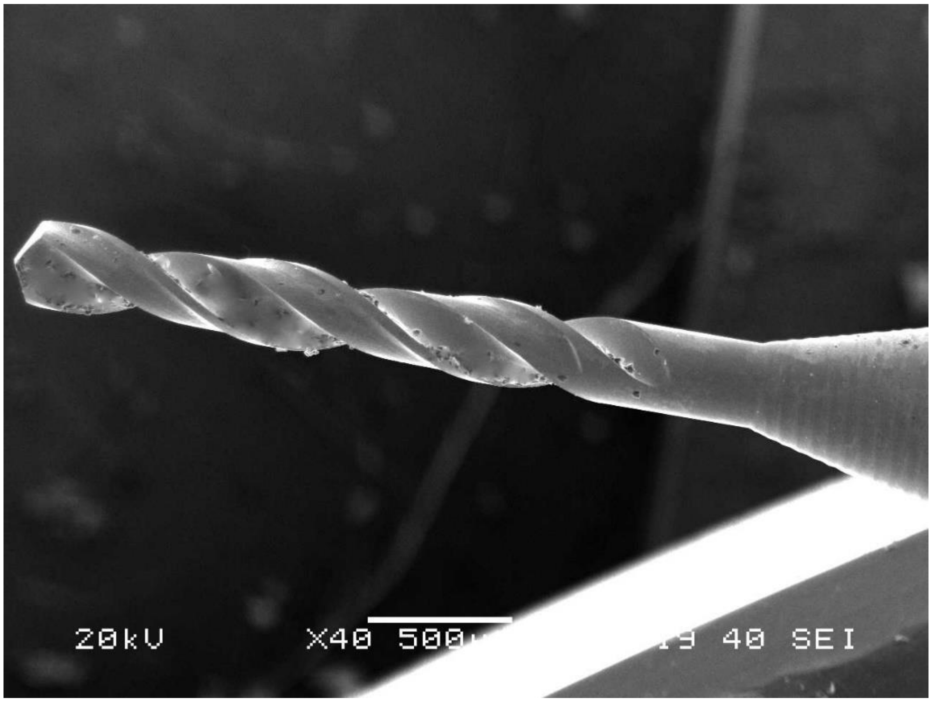


Fig 4: SEM image of tool before machining

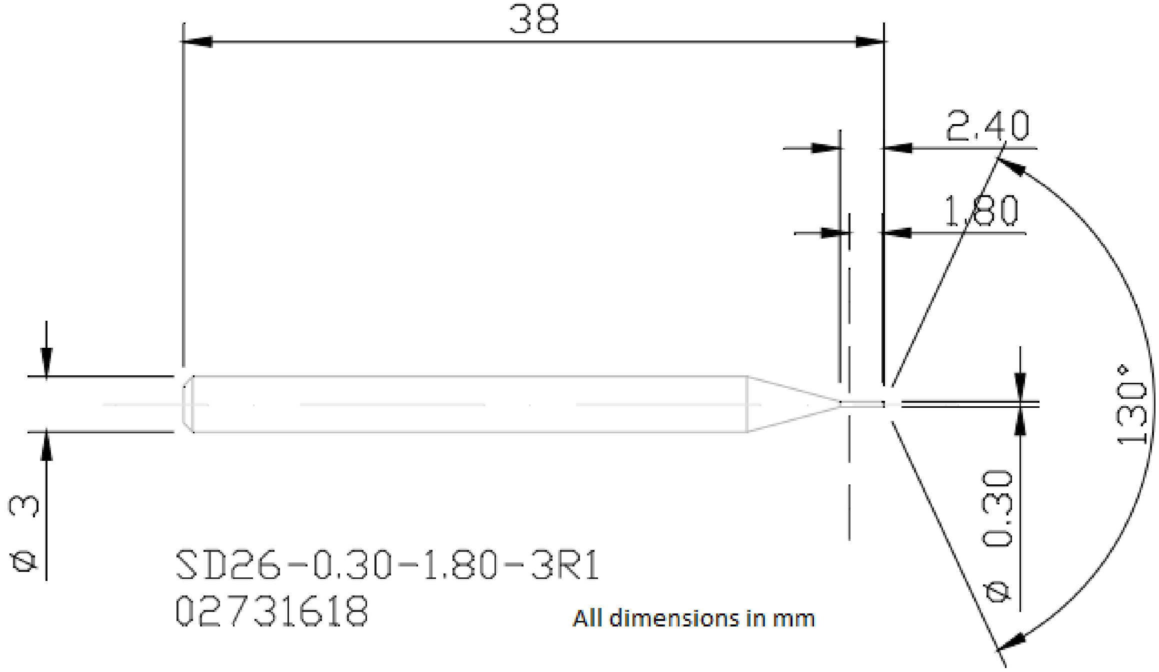


Fig.5: Drafting of model of drill bit.

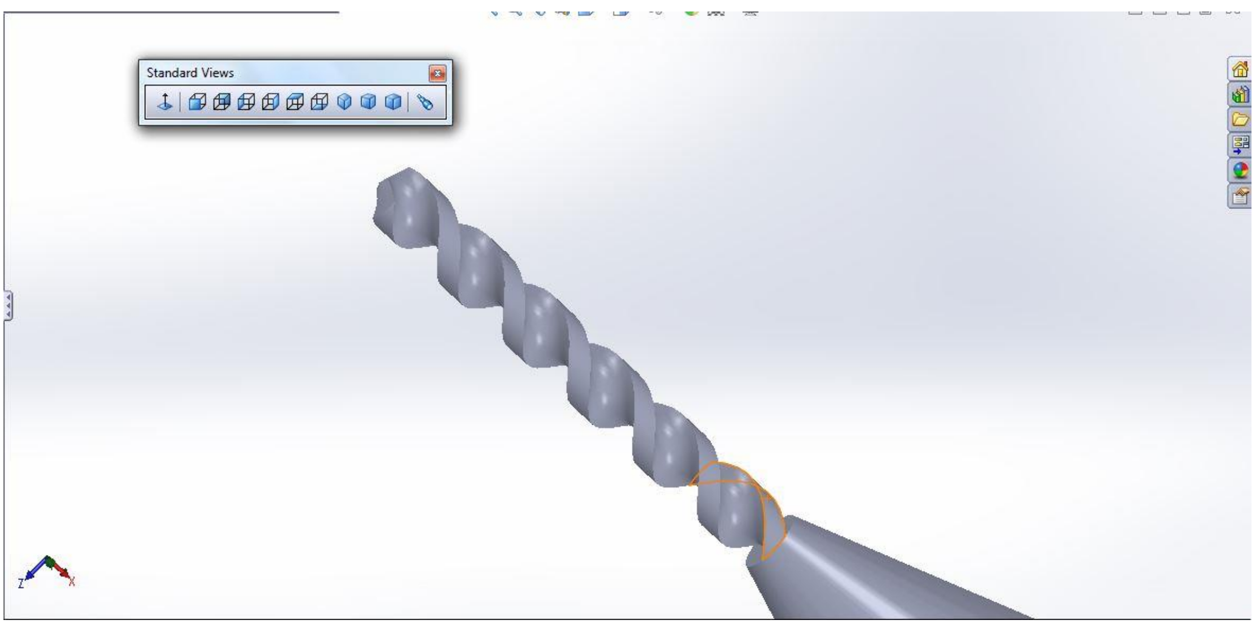


Fig.6: Enlarged view of the flute of the micro-drill in SOLIDWORKS.

Table 1: Tool specification & material properties

Tool specifications	Tool material	Cemented carbide (WC-6%Co)
	Diameter of the tool	0.3 mm
	Length of the insert	38 mm
	Point angle	130°
	Shank diameter	3 mm
Material properties	Density	150000 kg/m^3
	Ultimate tensile strength	1516.84 MPa
	Ultimate tensile strength	5300 MPa (approx.)
	Transverse rupture strength	2300 MPa (approx.)
	Hardness Rockwell	A89-92
	Modulus of elasticity	637000 MPa (approx.)
	Poison’s ratio	0.26

Table 2: Specification of the CNC Machine

Machine	Maxmill, MTAB, Bangalore
Axis travel (X*Y*Z)	300*250*250 mm^3
Table clamping surface	500*350 mm^2
T slots (number*size)	3*14 mm
Spindle motor	Beta 3/10000i (Max speed:10000rpm)
ATC make	MACO
Tool type	BT30

Table 3: Experimental conditions

Spindle speed	3600 rpm
Feeds	1,3,5 mm/min
Retraction	1 mm
Incremental depth	50 µm
Depth of cut	1.25 mm

The work piece with drilled hole was observed under scanning electron microscope (SEM) (Make: NOVA NANO SEM-450). The images of the holes with high magnifications were taken and analyzed. Each hole was approximated by three circles whose circumference closely matched the periphery of the hole. The mean of the three diameters was taken as the hole diameter (D_h). Similarly three readings for burr thickness at different locations were taken and the mean burr thickness was estimated for each hole.

For measurement of delamination factor, a circle covering all the delamination damages was plotted which was concentric with the circle, approximated to be the periphery of the hole. The diameter of the outer hole was measured (D_{lam}).The delamination factor was calculated as follows [12].

Delamination factor (F_d) = D_{lam} / D

Where D_{lam} is the diameter of the delaminated zone and D is the nominal tool diameter.

CAD Modelling and ANSYS Analysis

A 3D model of the micro drill bit with given specifications was drawn using SOLIDWORKS with the dimensions shown in Table 1. FEA-based simulation for deformation, maximum principal stress and maximum shear stress was carried out using ANSYS 15.0 workbench software. For analysis of stress and deformation in drill bit, torque and thrust force data are necessary. Thrust force and torque data for peck drilling were obtained from predictive power model discussed in reference [11]. The values of thrust force and torque were loaded into the model for simulation. The 3D model was imported to ANSYS. After defining the tool material and the physical and material properties, meshing was carried out with the specifications with relevance 100, fine relevance center and minimum edge length 0.04375 mm. The drill bit after meshing is shown in Fig. 7. The model was then solved for the required output data.

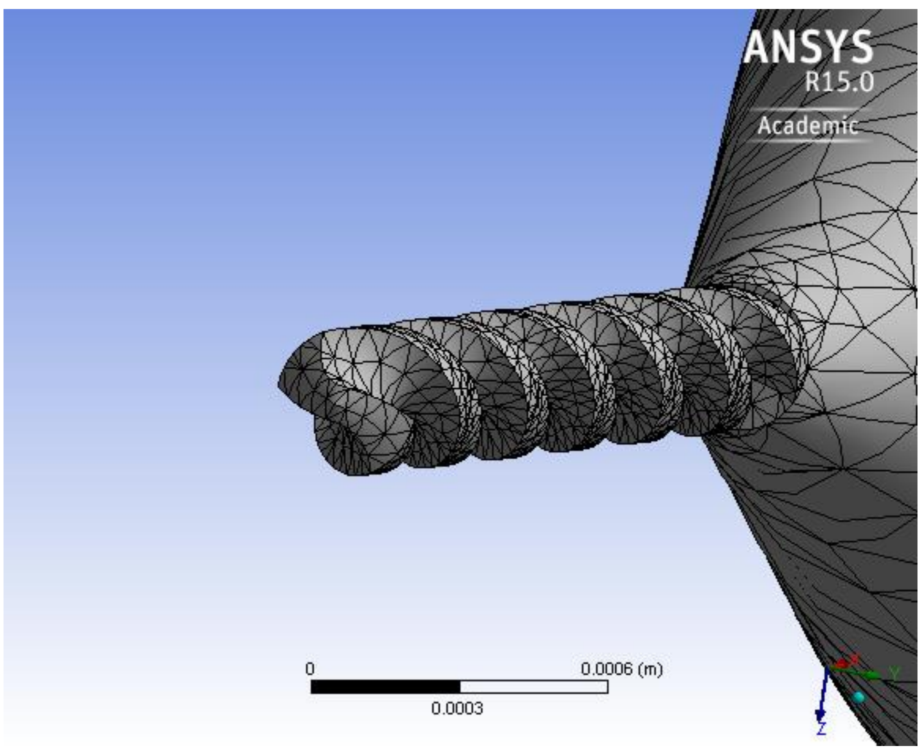


Fig 7: Drill bit after meshing

CHAPTER 4

RESULTS AND DISCUSSION

The maximum value of maximum principal stress and deformation obtained from the simulation and analysis are tabulated along with the cutting conditions (spindle speed and feed) in Table 3. The force, torque along with the obtained deformation and maximum principal stress value are tabulated in Table 4.

Table 4: Results of analysis along with input parameters

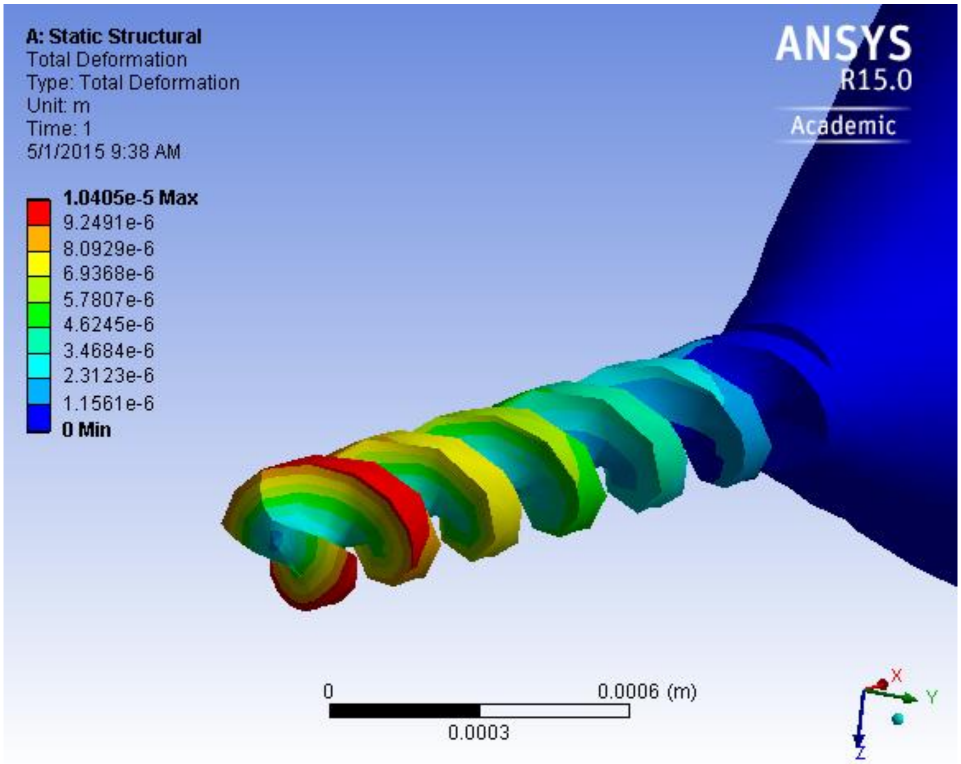
Spindle speed (rpm)	Feed (mm/min)	Thrust force (N)	Torque(N-mm)	Maximum Deformation (µm)	Maximum principal stress (MPa)
	1	0.679	0.968	10.405	1225.9
3600	3	0.955	1.199	12.846	1508.4
	5	1.120	1.325	14.172	1661.3

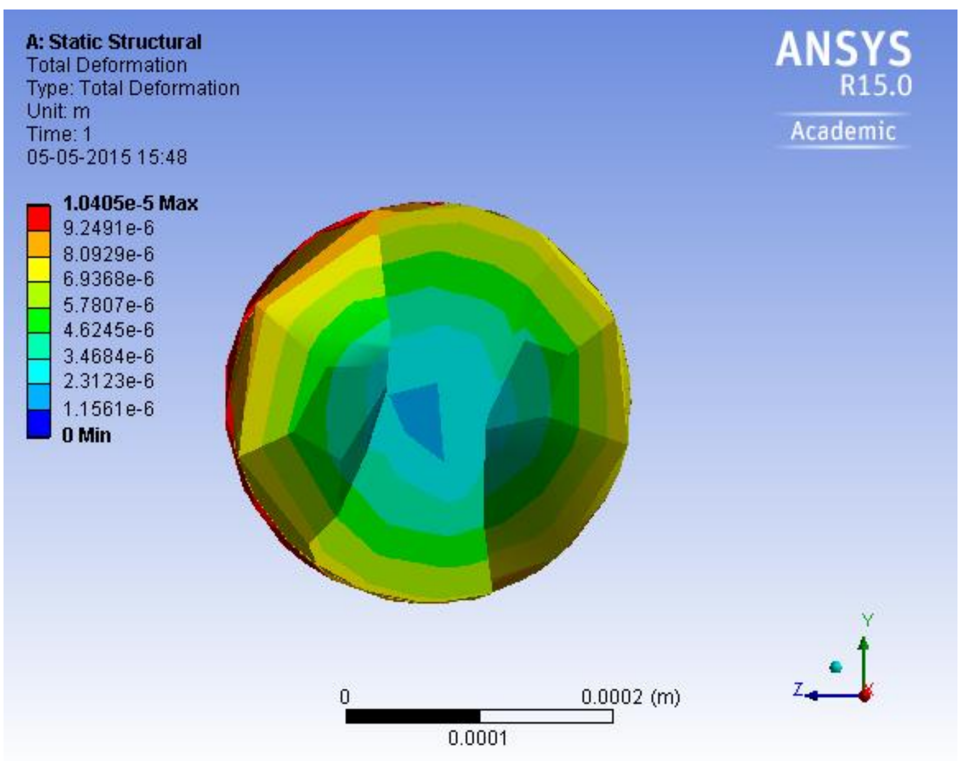
Deformation

It is clearly evident from the deformation profile (Fig 8(a), (b) and (c)) that maximum deformation occurs around the cutting edge. It may be attributed to the direct contact of the tool with the work piece and the cutting torque which acts around the periphery of the drill bit. With increase in feed, the thrust force and cutting torque increases resulting in hike in deformation.

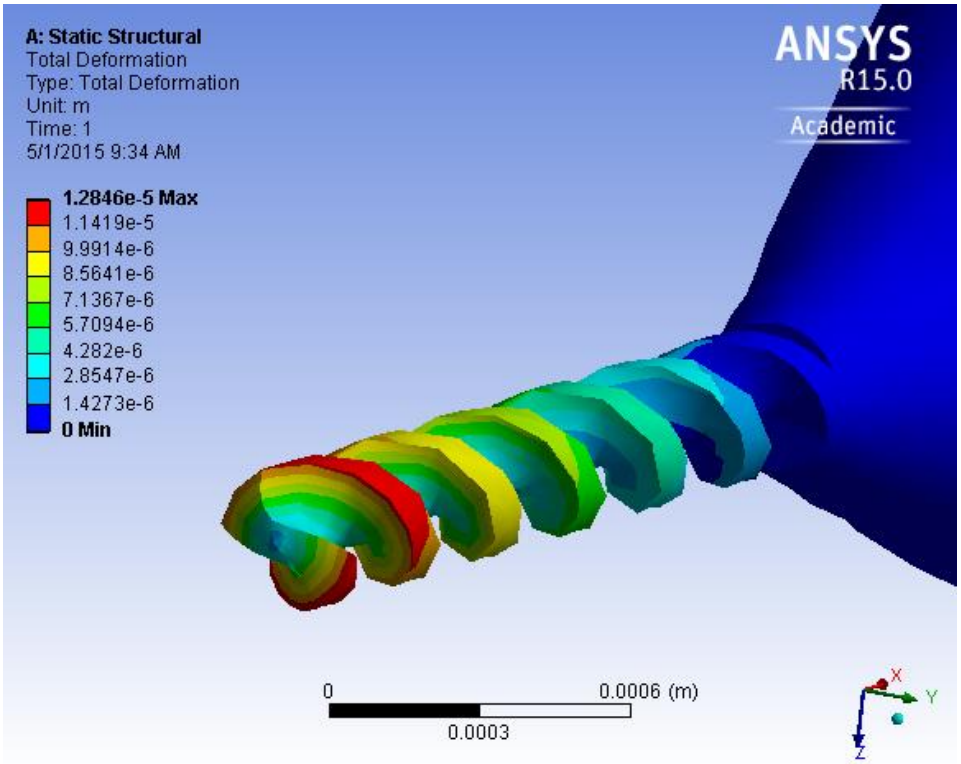
Maximum principal stress

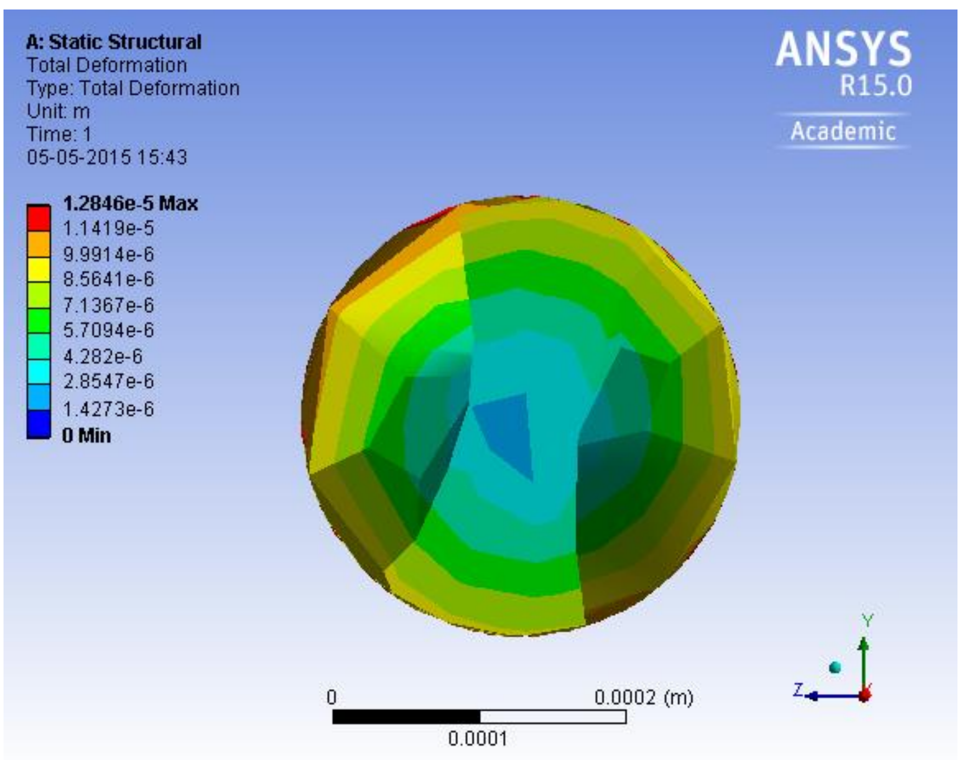
Stress profile in the flute of the drill bit is shown in Fig. 9((a), (b) and (c)). Tungsten carbide has a tendency to fail through brittle fracture [13]. So the failure criteria will be validated by maximum principal stress criteria. Maximum stress was found at the web. Minimum cross sectional area of the flute experiences the maximum stress because of the combined effect of axial thrust force and the twisting moment due to cutting torque.


A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
5/1/2015 9:38 AM
1.0405e-5 Max
9.2491e-6
8.0929e-6
6.9368e-6
5.7807e-6
4.6245e-6
3.4684e-6
2.3123e-6
1.1561e-6
0 Min
ANSYS
R15.0
Academic
0
0.0006 (m)
0.0003
X
Y
Z

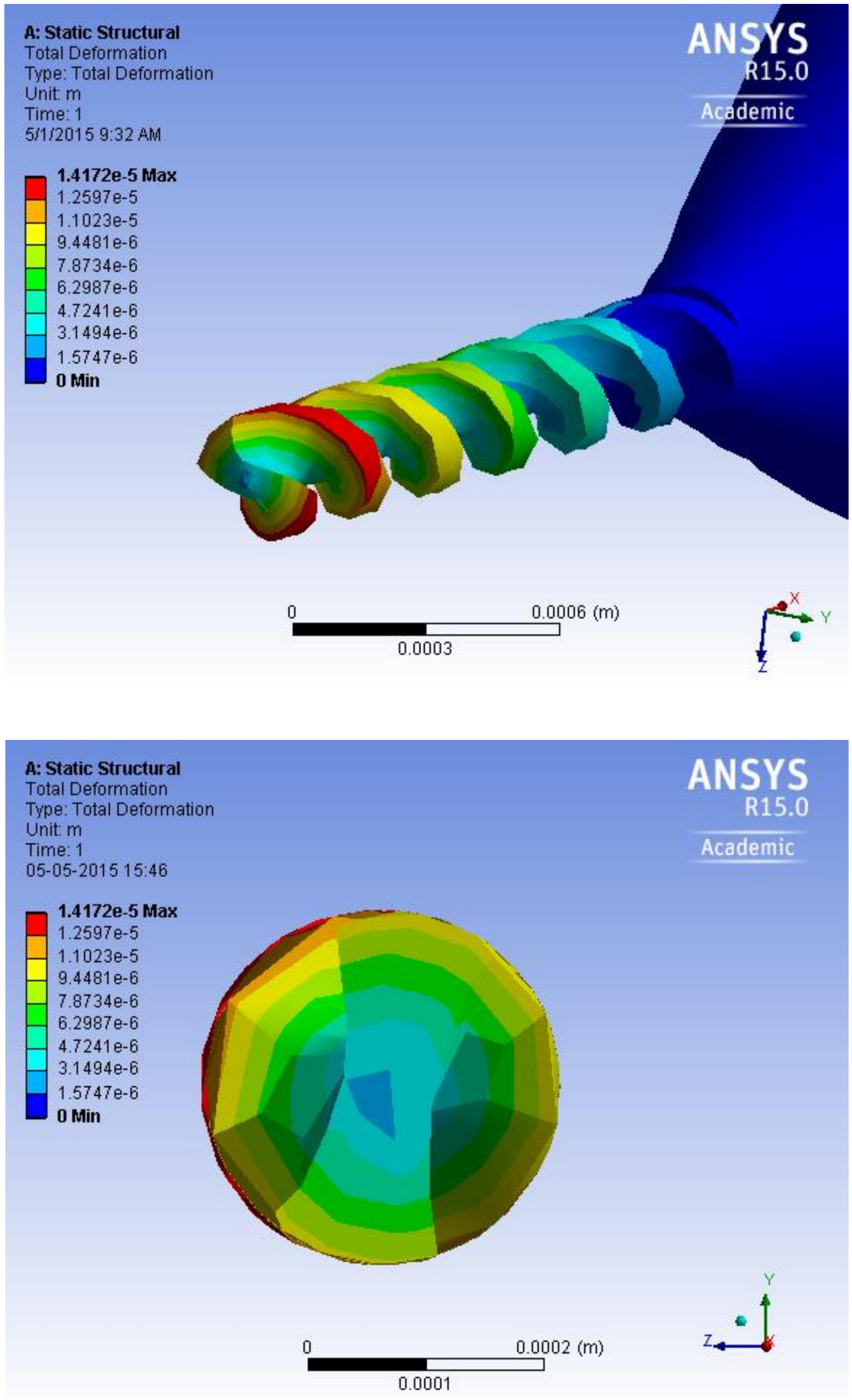

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
05-05-2015 15:48
1.0405e-5 Max
9.2491e-6
8.0929e-6
6.9368e-6
5.7807e-6
4.6245e-6
3.4684e-6
2.3123e-6
1.1561e-6
0 Min
ANSYS
R15.0
Academic
0
0.0002 (m)
0.0001
Y
Z

(a)


A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
5/1/2015 9:34 AM
1.2846e-5 Max
1.1419e-5
9.9914e-6
8.5641e-6
7.1367e-6
5.7094e-6
4.282e-6
2.8547e-6
1.4273e-6
0 Min
ANSYS
R15.0
Academic
0
0.0006 (m)
0.0003
X
Y
Z

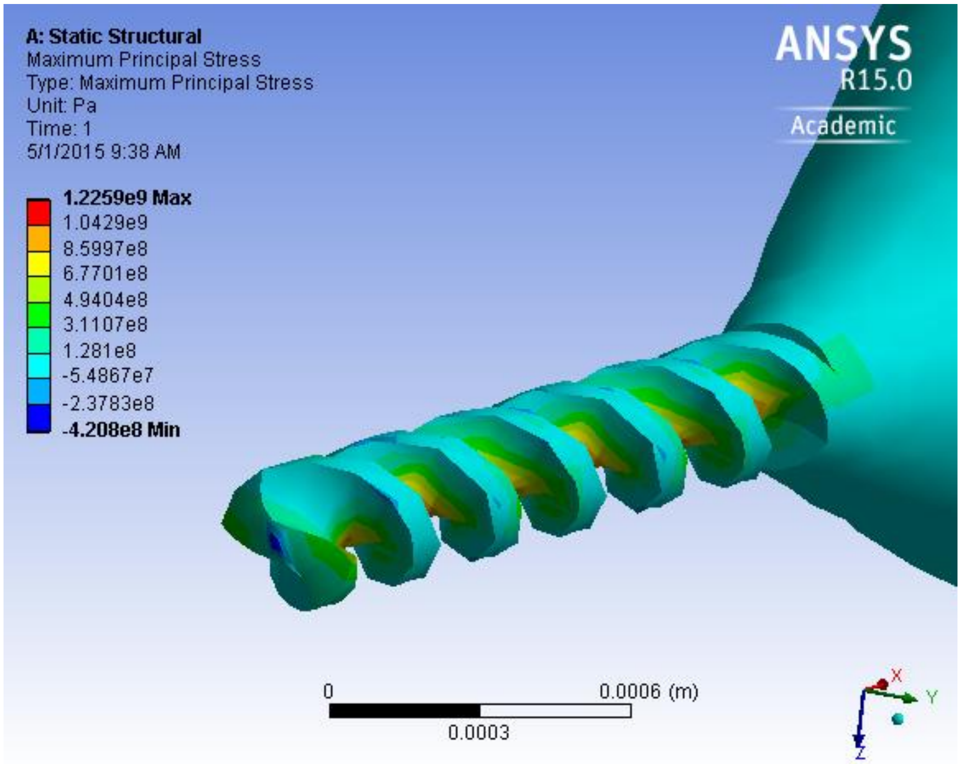

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
05-05-2015 15:43
1.2846e-5 Max
1.1419e-5
9.9914e-6
8.5641e-6
7.1367e-6
5.7094e-6
4.282e-6
2.8547e-6
1.4273e-6
0 Min
ANSYS
R15.0
Academic
0
0.0002 (m)
0.0001
Y
Z

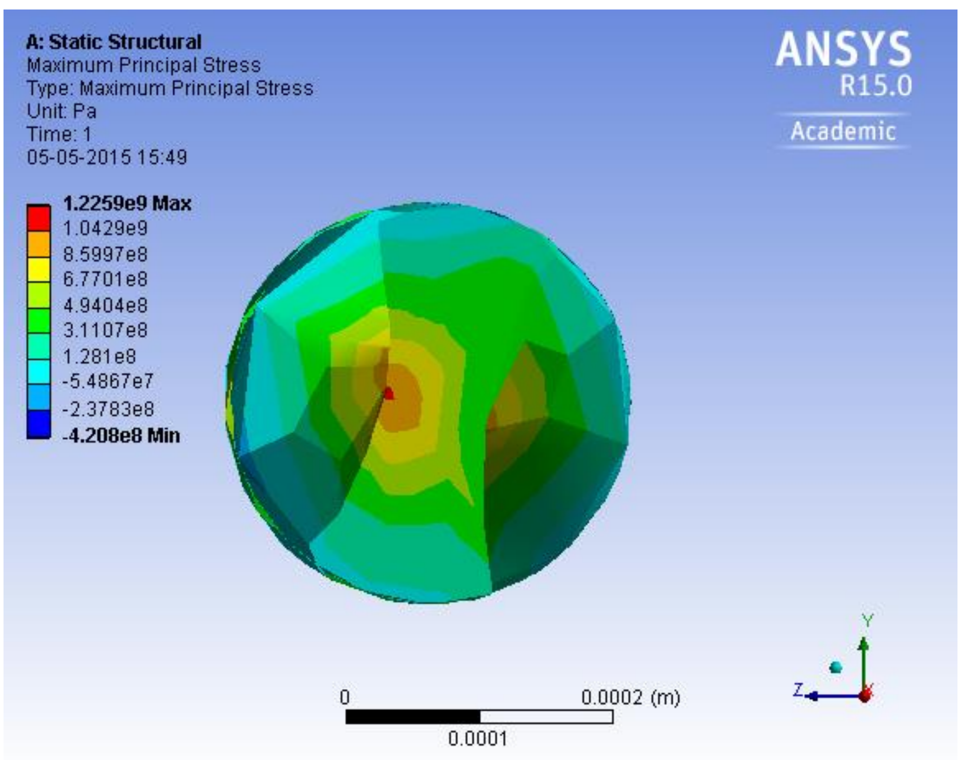
(b)



(c)

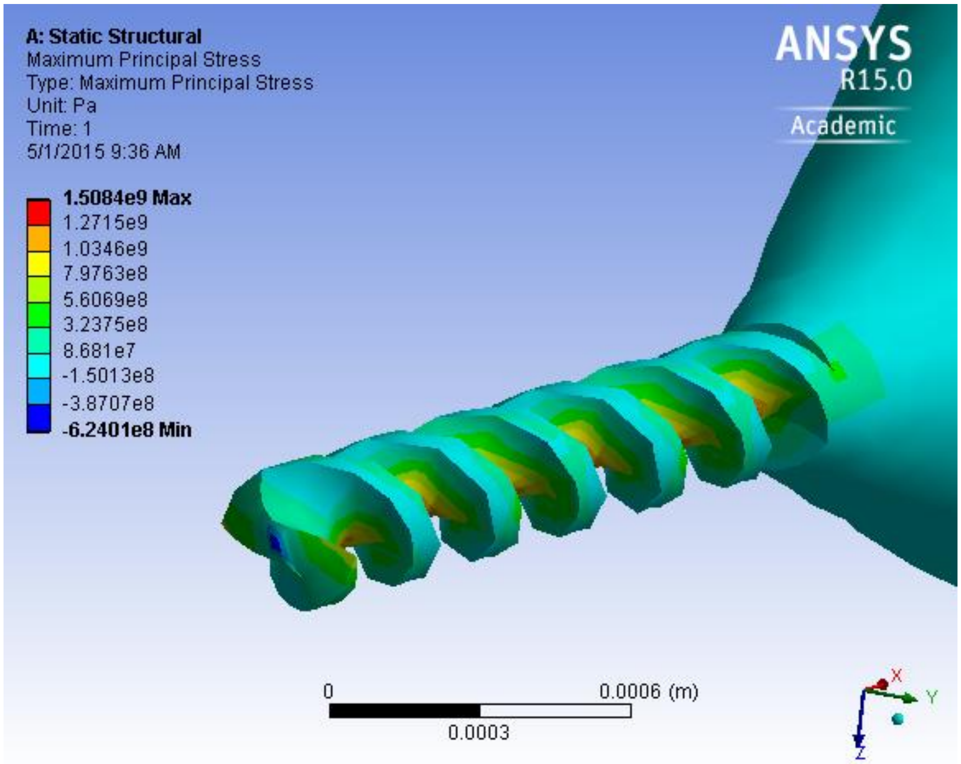
Fig.8: Total deformation in axial and diametrical plane with feed (a) 1mm/min (b) 3mm/min(c) 5 mm/min.

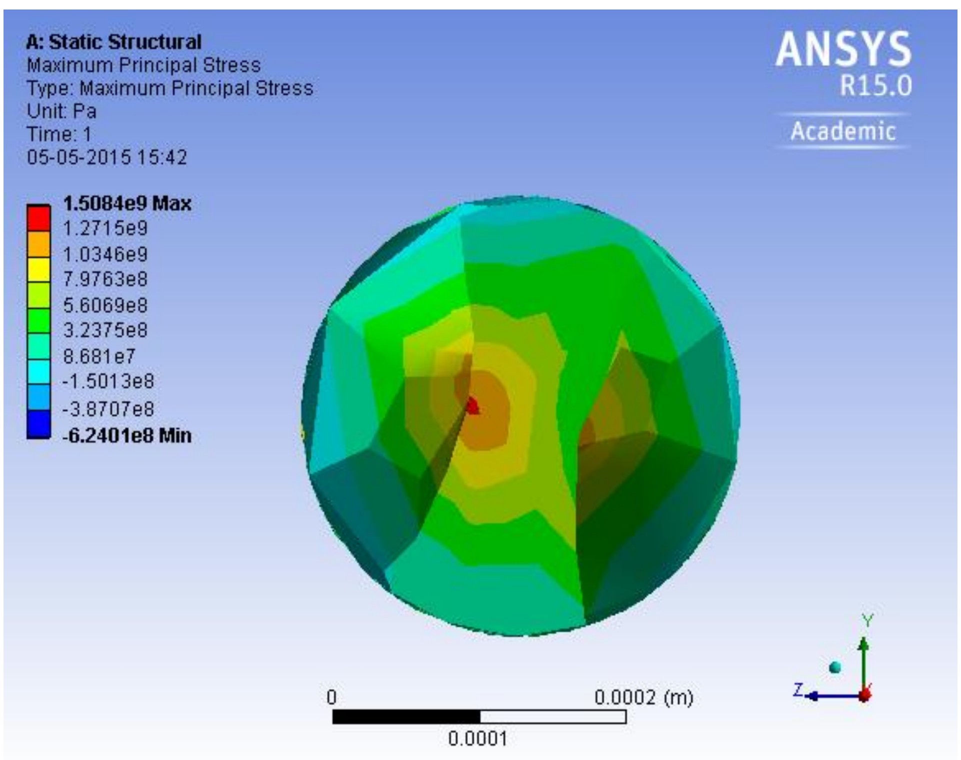

A: Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1
5/1/2015 9:38 AM
1.2259e9 Max
1.0429e9
8.5997e8
6.7701e8
4.9404e8
3.1107e8
1.281e8
-5.4867e7
-2.3783e8
-4.208e8 Min
ANSYS
R15.0
Academic
0
0.0006 (m)
0.0003
X
Y
Z


A: Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1
05-05-2015 15:49
1.2259e9 Max
1.0429e9
8.5997e8
6.7701e8
4.9404e8
3.1107e8
1.281e8
-5.4867e7
-2.3783e8
-4.208e8 Min
ANSYS
R15.0
Academic
0
0.0002 (m)
0.0001
Y
Z

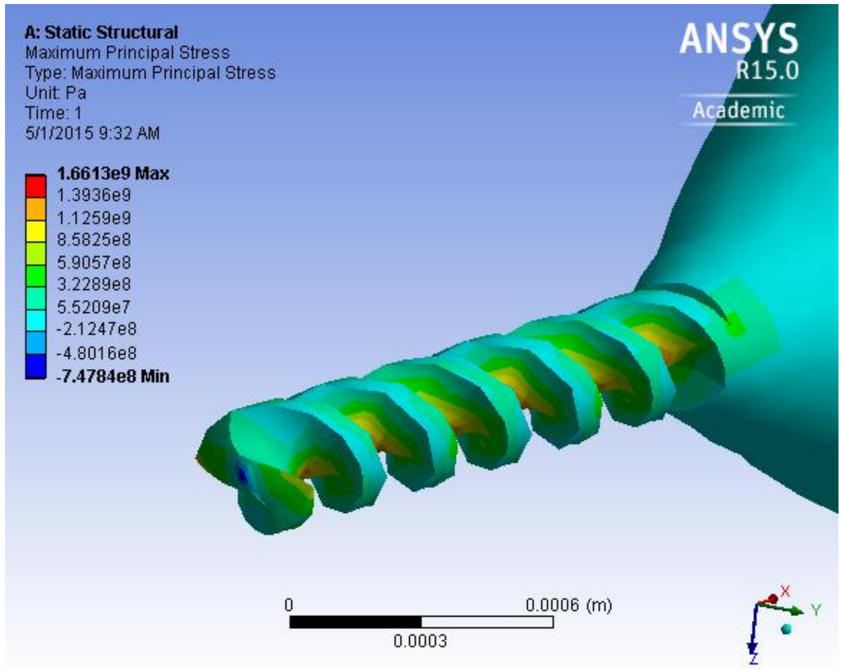
(a)

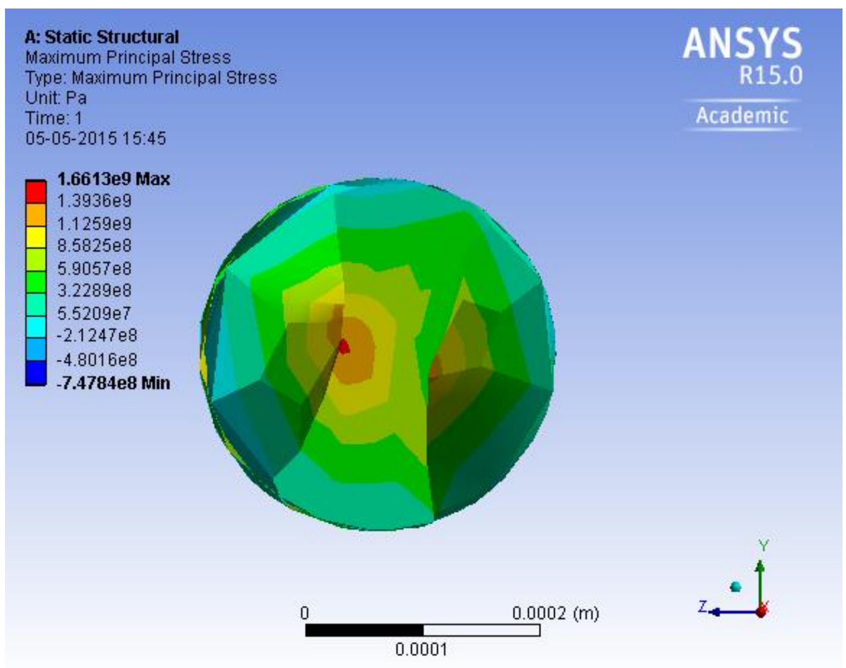
(b)


A: Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1
5/1/2015 9:36 AM
1.5084e9 Max
1.2715e9
1.0346e9
7.9763e8
5.6069e8
3.2375e8
8.681e7
-1.5013e8
-3.8707e8
-6.2401e8 Min
ANSYS
R15.0
Academic
0
0.0006 (m)
0.0003
X
Y
Z


A: Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1
05-05-2015 15:42
1.5084e9 Max
1.2715e9
1.0346e9
7.9763e8
5.6069e8
3.2375e8
8.681e7
-1.5013e8
-3.8707e8
-6.2401e8 Min
ANSYS
R15.0
Academic
0
0.0002 (m)
0.0001
Y
Z

(b)





(c)

Fig.9: Maximum Principal Stress in axial and diametrical plane with feed (a) 1mm/min (b) 3mm/min(c) 5 mm/min.

Effect of Feed on Various Hole Quality Characteristics

A representative SEM micrograph depicting various characteristics such as diameter, delamination damage and burr height of a micro hole drilled on PCB in Fig. 10. Effect of feed on these characteristics is discussed as follows. SEM images of micro holes obtained after drilling with different feed rates are shown in Fig. 11((a), (b) and (c)).

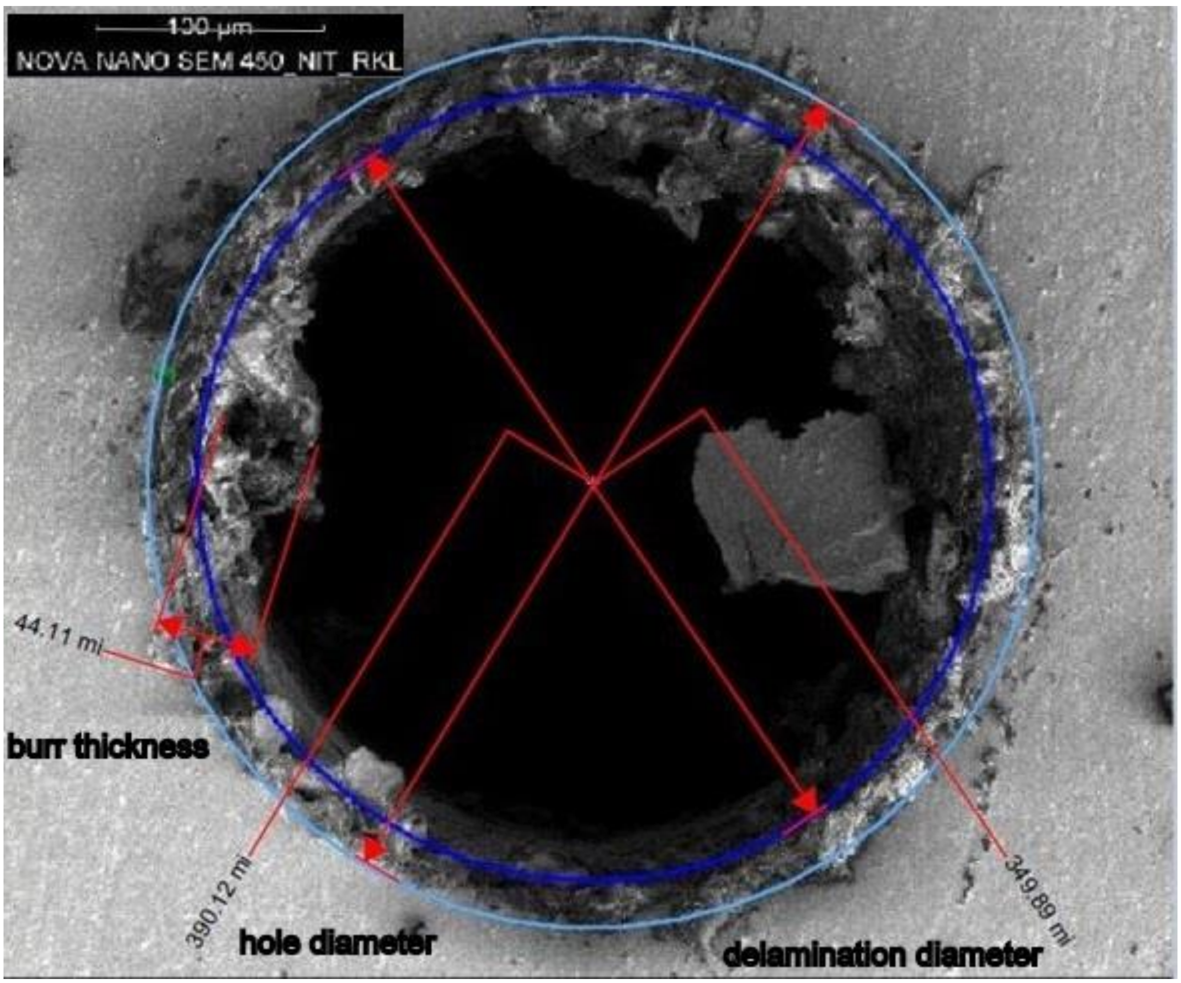
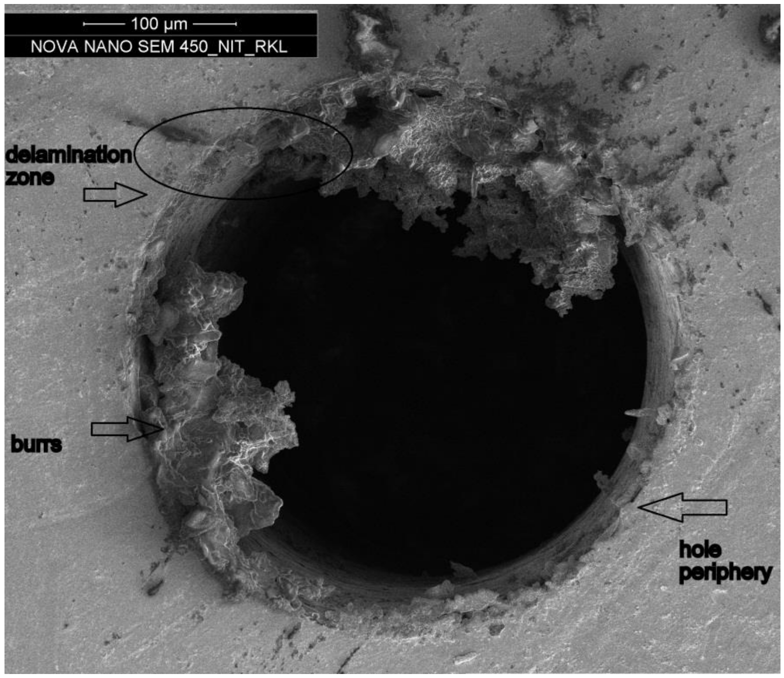


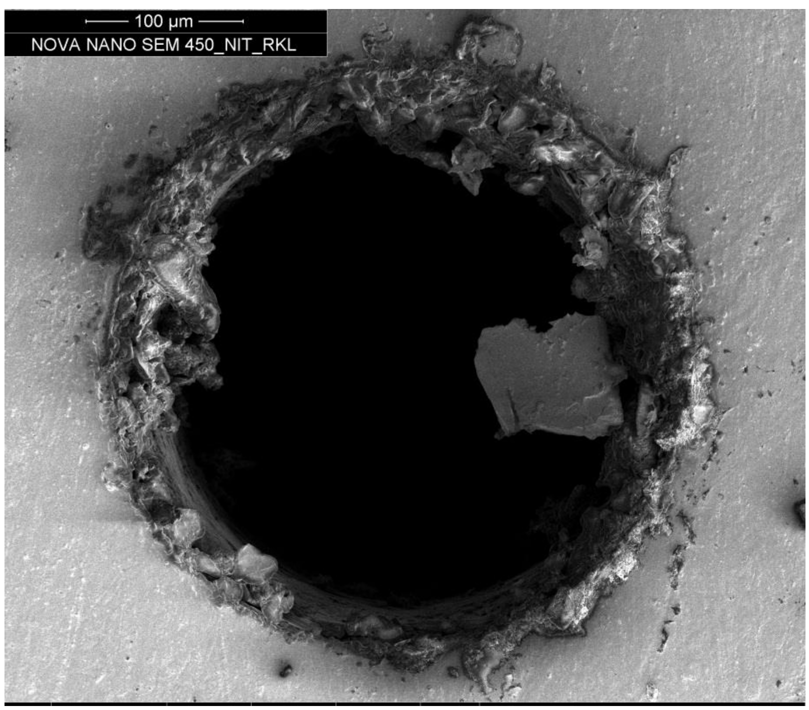
Fig.10: Measurement of hole quality parameters.

Table 5: Hole quality parameters

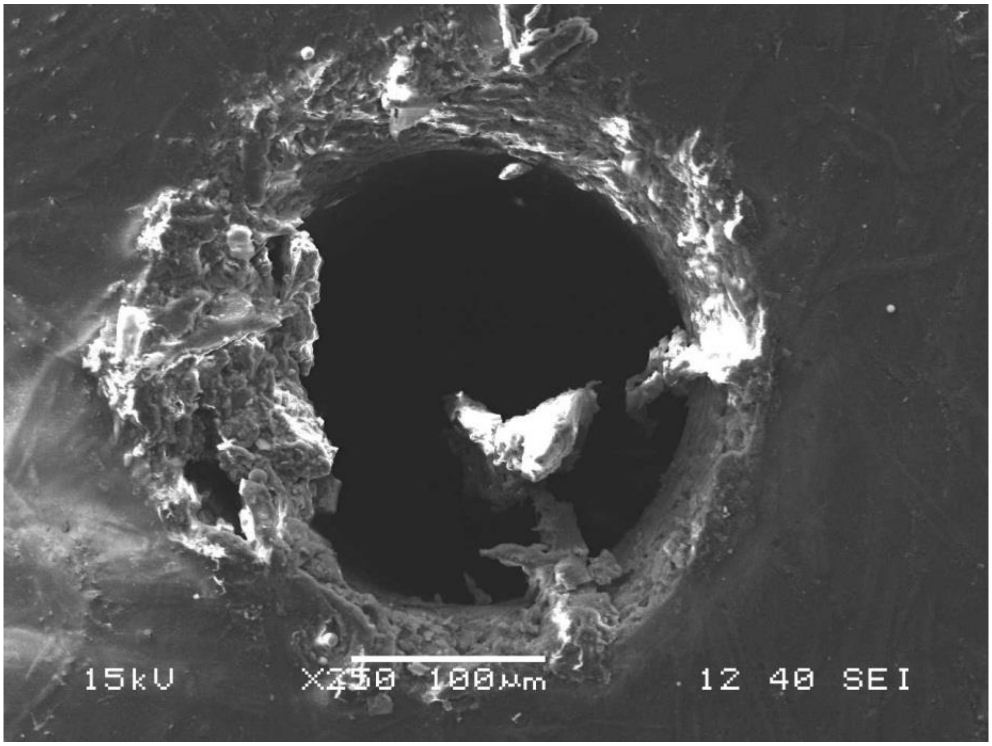
Feed (mm/min)	**Hole no.**	**Diameter (μm)**	**Delamination factor**	**Burr thickness (μm)**
1	1	366.76	1.313	31.01
1	2	367.86	1.336	33.93
1	3	373.94	1.347	42.30
1	4	353.11	1.251	45.03
3	1	340.96	1.427	39.16
3	2	349.89	1.343	44.11
3	3	328.45	1.381	46.16
3	4	343.57	1.406	52.32
5	1	322.22	1.412	48.31
5	2	274.72	1.392	47.04
5	3	318.53	1.426	53.22
5	4	306.27	1.151	67.89


100 µm
NOVA NANO SEM 450_NIT_RKL
delamination
zone
burrs
hole
periphery

(a)


100 µm
NOVA NANO SEM 450_NIT_RKL

(b)



(c)

Fig.11: Representative hole images with feed (a) 1 mm/min and (b) 3mm/min (c) 5mm/min.

Diameter

It is observed that there is an increase in diameter of the hole with respect to nominal drill size. This is caused due to the formation of built up layer (BUL) or built up edge (BUE) on the rake surface of the micro drill. An SEM micrograph depicting the material build up is shown in Fig. 12. Variation of diameter of micro holes with feed rates is graphically represented in Fig. 13. It is evident that increase in feed rate led to reduction in diameter of the holes. However, no significant variation of diameter is observed with number of holes drilled.

ANSYS simulation results clearly indicated the increase in load exerted by the drill bit on the hole surface with increase in feed. Additionally there will be increase in machining zone temperature. The combined effect of thermal and mechanical deformation would cause a non-uniform deformation in the form of inward expansion owing to non-homogeneous and anisotropic properties of different layers of materials in PCB. Besides during low speed & feed machining, the interaction time between the tool & the work piece increases which may be another reason of larger holes at low feeds.

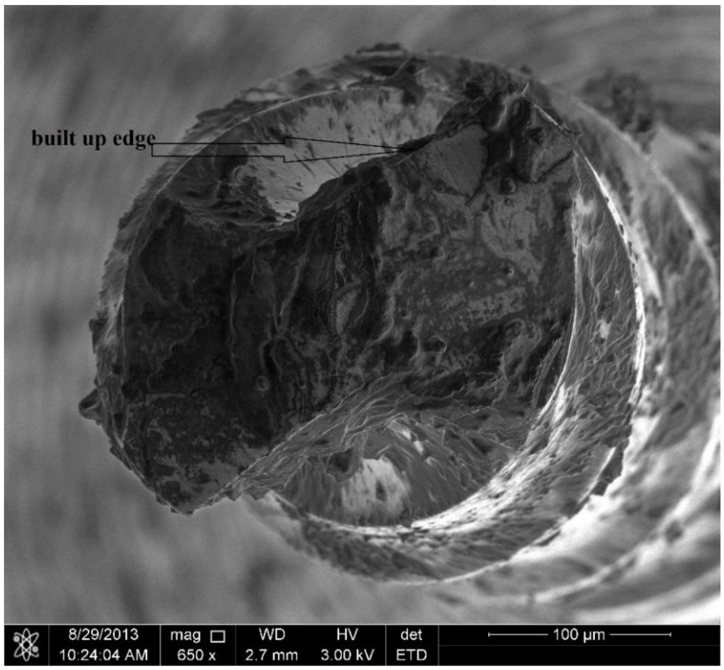


Fig. 12. SEM image of drill bit depicting Built up edge.

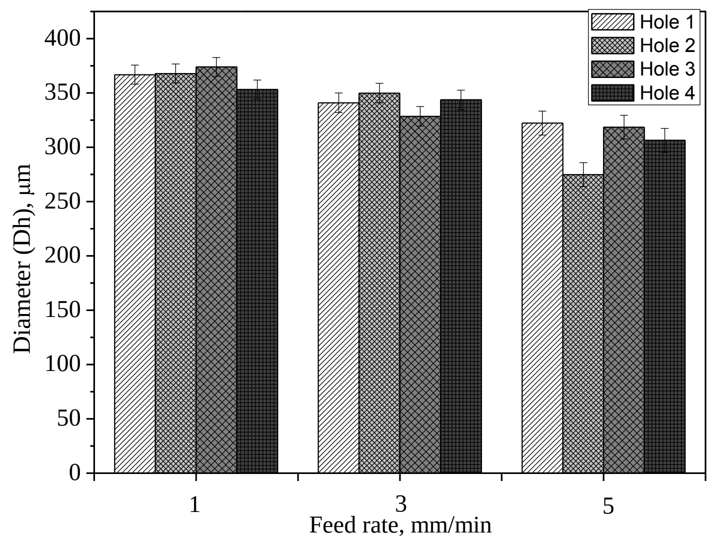


Fig. 13. Variation of diameter of drilled hole with feed rate.

Delamination Factor

Delamination is one of the major concerns in micro drilling of composite materials for which thrust force and torque are primarily responsible. The torque generates shear stress and weakens the top layers around the periphery. The thrust force which is perpendicular to the layers causes the separation. When the thrust force overcomes the inter-layer strength of the material, the separation takes place. Influence of feed on delamination can be revealed in Fig. 14 which shows increasing trend for different holes with increase in feed from 1mm/min to 5 mm/min. Variation of delamination with feed can be attributed to difference in resistance offered by multiple layers and the variation of the deformation of the tool as indicated in Fig. 15. Another mechanism responsible for delamination might be spiraling of material on drill flute before getting separated from the work piece. The temperature rise associated with increase in feed softens the work material; as a result more material stick to the flute & the delamination damage increases. This fact can be ascertained with the help of SEM image shown in Fig. 16.

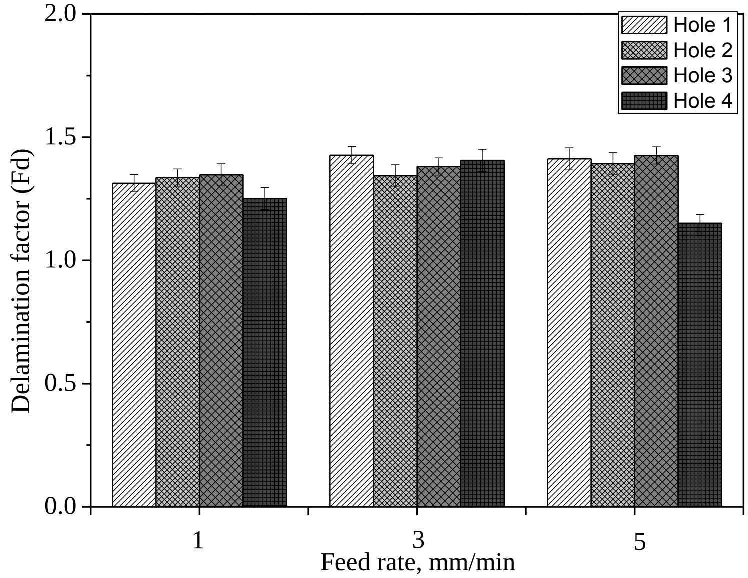


Fig. 14. Variation of delamination factor with feed rate.

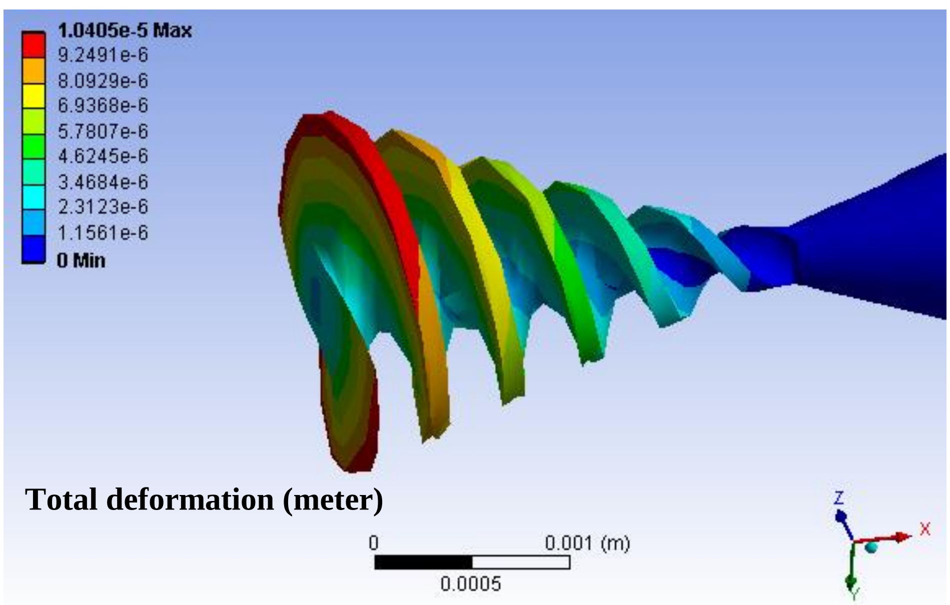


Fig. 15. Different deformations in different layers of drill bit.

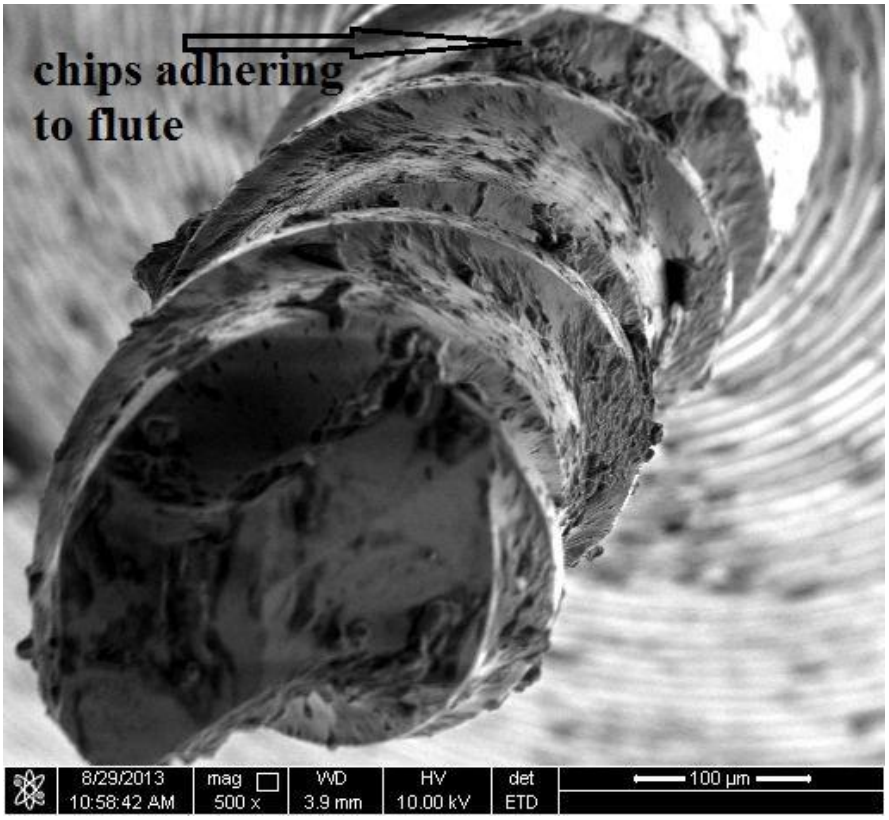


Fig. 16. SEM image of the drill bit showing chips adhering to flute after drilling (feed: 3 mm/min, hole no: 4).

Burr Thickness

In through hole drilling, burrs are formed in both entry and exit sides. Formation of burrs are also influenced by drill geometry like point angle, helix angle, relief angle, material properties like hardness, ductility, toughness and cutting conditions like cutting speed, feed, tool wear etc. [31]. Generally burrs are formed due to plastic deformation of exit surface.

As the feed increased, due to the presence of more material in front of cutting edge, there would be significant load encountered by the cutting edge. This would increase the possibility of wear. As a result tendency of shear comes down; rubbing and ploughing becomes predominant, thereby increasing the plastic deformation on the hole surface.

It is interesting to know that there was an increase in burr thickness with progressive drilling of micro holes. This phenomenon might be described through gradual wear owing to indentation of chisel edge and adhesion of work material on chisel and cutting edges. This is also evident from Fig. 17. This led to significant increase in plastic deformation causing burr thickness to increase with the number of drilled holes.

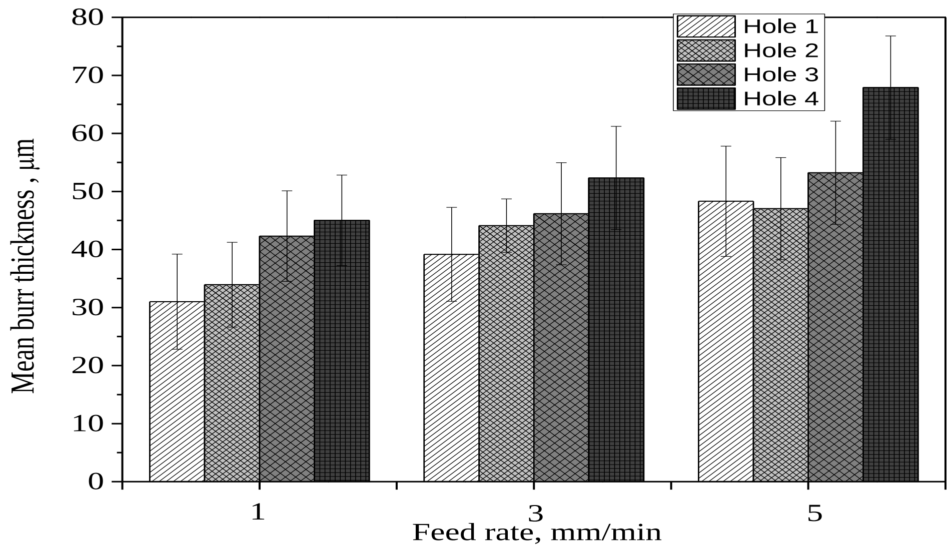


Fig. 17. Variation of mean burr thickness with feed rate.

CHAPTER 5

CONCLUSION

The present work aimed at investigating the influence of feed rate on various machining characteristics during micro drilling of PCB with the help of simulation and experimentation. The effect of feed on deformation and various stresses was simulated.

The findings of the current study are as follows:

- Results indicated increasing trend of deformation and stresses acting on a micro drill bit with feed. Maximum principal stress occurred on rake surface very close to the cutting edge while maximum deformation occurred around the periphery of the micro drill.
- Rise in feed rate led to reduction in hole diameter which can be attributed to the formation of built up edge and higher interaction time at low feed.
- Delamination factor increased with increase in feed due to the variation of deformation in different layers of drill bit and due to spiraling of material on the drill flute.
- Burr thickness increased with increase in feed. It can be explained by the increased tool wear at higher feed.
- Moreover, burr thickness increased when a sequence of four holes was drilled with a particular feed.

Variation of these characteristics has also been explained with the help of simulated results. Therefore, simulation of micro drilling process has been found to be an effective way to explain various characteristics of micro holes drilled in PCBs.

Future Scope

Simulation results obtained from the current study has opened up significant scope of research in the field of micro-drilling of PCBs. The result of simulation can be further utilized in explaining various phenomena such as tool failure, surface integrity including surface roughness of drilled hole, burr height and chip characteristics. Effect of cutting speed and drill diameter can also be evaluated on these machining characteristics and optimal combination of process parameters may be determined by using multi response optimization techniques.

BIBILOGRAPHY

[1]Kim, C.; Bono, M.; Ni, J. (2002) Experimental analysis of chip formation in micro-milling. NAMRI/SME, 30: 247–254.

[2] Chae, J.; Park, S.S.; Freiheit, T. (2006) Investigation of micro-cutting operations. International Journal of Machine Tools & Manufacture, 46: 313–332.

[3] Liu, X.; DeVor, R.E.; Kapoor, S.G.; Ehmann, K.F. (2004), The mechanics of machining at the micro-scale: assessment of the current state of the science. Journal of Manufacturing Science and Engineering, 126:666–678.

[4] Nakagawa, H.; Ogawa, K.; Kihara, A.; Hirogaki, T.; Improvement of micro-drilled hole quality for printed wiring boards, Journal of Materials Processing Technology 191 (2007) 293–296

[5] Bhandari,B.;Hong,Y.;Yoon,H.;Moon,J.; Pham,M.; Lee,G.; Huang,Y.; Linke, B. S.; Dornfeld, D.A.; Ahn, S. ; Development of a micro-drilling burr-control chart for PCB drilling, Precision Engineering 38 (2014) 221– 229

[6] Anand, R.S.; and Patra,K.; Modeling and simulation of mechanical micro-machining—a review, Machining Science and Technology, 18:323–347, ISSN: 1091-0344 print /1532-2483

[7] Wang,L.; Zheng , L.; Wang,C.Y.; Li,S.; Song,Y.; Zhang,L.; Sun,P.; "Experimental study on micro-drills wear during high speed of drilling IC substrate", (2014) Circuit World, Vol. 40 Iss: 2, pp.61 – 70

[8] Zheng,X.; Liu,Z.; An,O. Wang,X.; Xu,Z.; Chen,M.; "Experimental investigation of microdrilling of printed circuit board", Circuit World, Vol. 39 (2013) Iss: 2, pp.82 – 94

[9] Capello,E.; Workpiece damping and its effect on delamination damage in drilling thin composite laminates, Journal of Materials Processing Technology Volume 148, Issue 2, 15 May 2004, Pages 186–195

[10] Rahamathullah,I.; and Shunmugam,M.S.; Analyses of forces and hole quality in micro-drilling of carbon fabric laminate composites, Journal of Composite Materials 0(0) 1–12

[11] Rahamathullah,I.; and Shunmugam,M.S.; Thrust and torque analyses for different strategies adapted in microdrilling of glass-fibre-reinforced plastic, Proc. IMechE Vol. 225 Part B: J. Engineering Manufacture

[12] Imran,M.; Mativenga,P.T.; Gholinia,A. & Withers,P.J.; Evaluation of surface integrity in micro drilling process for nickel-based super alloy, Int J Adv Manuf Technology (2011) 55:465–476

[13] Hinds, B.K.; Treanor, G.M. (2000) Analysis of stresses in micro-drills using the finite element method.International Journal of Machine Tools & Manufacture, 40: 1443–1456.

[14] Yongchen,P.; Qingchang,T.; Zhaojun,Y.; A study of dynamic stresses in micro-drills under high-speed machining, International Journal of Machine Tools & Manufacture 46 (2006) 1892–1900

[15] Yoon,H.; Bhandari,B.; Moon,J.;Kim,C.; Lee,G.; Park,K.W.;Song,C.; Ahn, S. ;Energy Analysis of Micro-drilling Process Used to Manufacture Printed Circuit Boards, 19th CIRP International Conference on Life Cycle Engineering, Berkeley, 2012

[16] Anand, R.S.; Patra,K.; Steiner,M.; Size effects in micro drilling of carbon fiber reinforced plastic composite, Prod. Eng. Res. Devel. (2014) 8:301–307

[17] Patra,K.; Anand, R.S.; Steiner,M.;and Biermann,D.; Experimental Analysis of Cutting Forces in Micro drilling of Austenitic Stainless Steel (X5CrNi18-10), Materials and Manufacturing Processes, 30: 248–255, 2015

[18] Imran,M.; Mativenga,P.T.; & Withers,P.J.; Assessment of machining performance using the wear map approach in micro-drilling, Int J Adv Manuf Technology (2012) 59:119–126

[19] Zheng , L.J.; Wang,C.Y.;Fu,L.Y.; Yang,L.P.;Qu,Y.P.; Song,Y.X.; Wear mechanisms of micro-drills during dry high speed drilling of PCB, Journal of Materials Processing Technology 212 (2012) 1989– 1997

[20] Zheng , L.J.; Wang,C.Y.; Qu,Y.P.; Song,Y.X.; Fu,L.Y.; Interaction of cemented carbide micro-drills and printed circuit boards during micro-drilling, Int J Adv Manuf Technol (2015) 77:1305–1314

[21] Imran,M.; Mativenga,P.T.; Gholinia,A. & Withers,P.J.; Comparison of tool wear mechanisms and surface integrity for dry and wet micro-drilling of nickel-base superalloys, International JournalofMachineTools&Manufacture76(2014)49–60

[22] Lee, D.G.; Lee, H.G. ; Kim, P.J.; Bang, K.G.; Micro-drilling of alumina green bodies with diamond grit abrasive micro-drills, International Journal of Machine Tools and Manufacture Volume 43, Issue 6, May 2003, Pages 551–558

[23] Chu, C.W.; Jang, J.S.C. ; Chen, H.W.; Chuang, T.L.; Enhanced wear resistance of the Cr-based thin film coating on micro drill by doping with W–C–N, Thin Solid Films Volume 517, Issue 17, 1 July 2009, Pages 5197–5201 4th International Conference on Technological Advances of Thin Films and Surface Coatings

[24] Giorleo, L.; Ceretti, E. ; Giardini, C.; ALD coated tools in micro drilling of Ti sheet, CIRP Annals - Manufacturing Technology Volume 60, Issue 1, 2011, Pages 595–598

[25] Kao, W.H.; Su, Y.L.; Yao, S.H.; Huang, H.C.; Optimizing the tribological properties and high-speed drilling performance of a-C:H coatings via nitrogen addition, Surface and Coatings Technology Volume 204, Issue 8, 15 January 2010, Pages 1277–1287

[26] Yao, S.H. ; Evaluation of TiN/AlN nano-multilayer coatings on drills used for micro-drilling, Surface and Coatings Technology Volume 197, Issues 2–3, 22 July 2005, Pages 351–357

[27] Kim,D.W.; Lee,Y.S.; Park,M.S.; Chu,C.N.; Tool life improvement by peck drilling and thrust force monitoring during deep-micro-hole drilling of steel, International Journal of Machine Tools and Manufacture Volume 49, Issues 3–4, March 2009, Pages 246–255

[28] Nam,J.S.; Lee,P.; Lee,S.W.; Experimental characterization of micro-drilling process using nano fluid minimum quantity lubrication, International Journal of Machine Tools and Manufacture Volume 51, Issues 7–8, July–August 2011, Pages 649–652

[29] Shi,H.;Li,H.; (2013) "Challenges and developments of micro drill bit for printed circuit board: a review", Circuit World, Vol. 39 Iss: 2, pp.75 – 81

[30] Gong, Y.; Ehmann, K.F.; Lin, C. (2003) Analysis of dynamic characteristics of micro-drills. Journal of Materials Processing Technology, 141: 16–28.

[31] Zheng , L.J.; Wang,C.Y.; Yang,L.P.;Qu,Y.P.; Song,Y.X.; Fu,L.Y.; Characteristics of chip formation in the micro-drilling of multi-material sheets, International Journal of Machine Tools & Manufacture 52 (2012) 40–49

[32] Zheng,X.; Dong,D.; Huang,L.; Wang,X.; Chen,M.; (2013) "Investigation of tool wear mechanism and tool geometry optimization in drilling of PCB fixture hole", Circuit World, Vol. 39 Iss: 4, pp.195 – 203.