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DESIGN AND OPTIMIZATION OF MILLING MULTI TIP CUTTER BY VARYING DEPTH PARAMETERS

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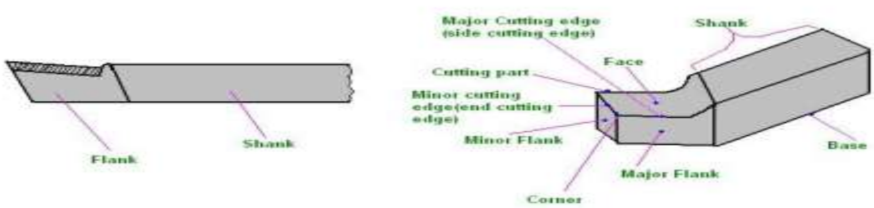
ABSTRACT One of the most important factors when cutting toughened materials is surface accuracy. Practical experience is typically necessary for setting the parameters of CNC machining operations. Sometimes, trial and error is even used to choose the settings, which increases the cost of the instrument and the production time. The number of cutting tool tips that are used in the cutter will result in an increase in surface finish; surface finish and tool wear are also correlated with the depth of cut. The depth of cut determines how complicated a specific tool design needs to be in order to machine complex profiles with a good surface quality. The two types of tools that are discussed in this work are the four flute bull nose cutter and the multi tip facing cutter. Surface finish will be compared and the differentiation in variable depth of cut with constant feed and speed in both situations will be optimised. With 4-tip cutters, the MEKINO 3-axis VMC was utilised for the experimental evaluation, and its parameters were optimised to improve surface finish.

Key words: surface finishing, flute and multi-tip cutters, CNC machining.

INTRODUCTION

Milling is the process of cutting away material by feeding a work piece past a rotating multiple tooth cutter. The cutting action of the many teeth around the milling cutter provides a fast method of machining. The machined surface may be flat, angular, or curved. The surface may also be milled to any combination of shapes. The machine for holding the work piece, rotating the cutter, and feeding it is known as the Milling machine. CNC milling is one of the most commonly used in industry and machine shops today for machining parts to precise sizes and shapes Among different types of milling processes, end milling is one of the most vital and common metal cutting operations used for machining parts because of its capability to remove materials at faster rate with a reasonably good surface quality Also, it is capable of producing a variety of shapes using milling cutter. In recent times, computer numerically controlled (CNC) machine tools have been used to make the milling process fully automated. It delivers greater enhancements in productivity, increases the quality of the machined parts and minimizes the production cost. For these reasons, CNC end milling process has been recently proved to be very versatile and useful machining operation in most of the modern manufacturing industries. Only the implementation of automation in milling process is not the last achievement. It is also necessary to optimize the process parameters for required quality.

1.1 Single Point Cutting Tool



Nomenclature of a single point cutting tool

Single point cutting tools have one principal cutting edge which is mainly used for cutting. These tools are used for turning, boring, planning etc. used in machines like lathe, boring and shaping machines. Single point cutting tools contain following parts: - shank (this is the main body of the tool), flank (which is adjacent below the cutting edge), face (the surface upon which chip slides), nose radius (it is the point where cutting edge intersects with side cutting edge). Machining operations are accomplished using cutting tools. The higher forces and temperatures during machining create a very harsh environment for the tool. If cutting force becomes too high, the tool fractures. If the cutting temperature becomes too high, the tool material softens and fails.

1.2Problem statement

The products manufactured today by using Press 4 tip Tools and Moulds require excellent accuracy with good surface finish. This totally depends on type of machining method and type of machining parameters used. Thus, precise control of parameters is required to optimize quality in manufacturing. Today Mould and Tool makers are using different variety of materials to manufacture tools and we know each material has different chemical composition with different properties. While optimizing the parameters used to obtain surface finish need to be kept same in order to achieve good surface finish.

2.0 LITERATURE REVIEW

D.Bhanuprakashetet al. (2013) had performed surface response methodology with Genetic algorithm for optimizing the process parameters for CNC milling. The raw materials used in this investigation were Aluminum alloy 6082 and Cemented carbide end mill of 12mm diameter and 30° helix angle was used. They concluded that The Regression analysis was conducted to develop mathematical model. **K.G.Durga Prasad et al. (2013)** had optimized material removal rate and surface roughness simultaneously; Data Envelopment Analysis was employed along with Taguchi method. The materials used in this investigation were Aluminum and carbide tool was used. They performed experiments using Taguchi L9 orthogonal array. They had taken L9 orthogonal array to perform experiments. Eighteen pockets were manufactured having different combination of parameters values according to Taguchi L18 orthogonal array. In order to establish a relationship between the performance measures and the process parameters, a set of additive models was produced. **Benardos &Vosniakos (2002)** presented a neural network modeling approach for the prediction of surface roughness (Ra) in CNC face milling. The data used for the training and checking of the networks' performance was derived from the experiments conducted on a CNC milling machine according to the principles of Taguchi's Design of Experiments (DoE) method. The factors considered in the experiment were the depth of cut, the feed rate per 28 tooth, the cutting speed, the engagement and wear of the cutting tool, the use of cutting fluid and the three components of the cutting force. **Tongchao Ding et al (2010)** experimentally investigated the effects of cutting parameters on cutting forces and surface roughness in hard milling of AISI H13 steel with coated carbide tools. Based on Taguchi's method, four-factor (cutting speed, feed, radial depth of cut, and axial depth of cut) four-level orthogonal experiments were employed. Three cutting force components and roughness of machined surface were measured, and then range analysis and ANOVA are performed. It is found that the axial depth of cut and the feed are the two dominant factors affecting the cutting forces. The validity of the model was proved through cutting experiment, and model was used, predict the machined surface roughness from the information on the cutting parameter analyzed the tool wear and the cutting force variation during high-speed end-milling Ti-6Al-4V alloy. The experimental results showed that the major tool wear mechanisms in high-speed end milling Ti-6Al-4V alloy with uncoated cemented tungsten carbide tools are adhesion and diffusion at the crater wear along with adhesion and abrasion at the flank wear. **Rajesh Kumar et al. (2014)** had performed GRA based Taguchi method to investigate the optimized design of the cutting process in end milling for Al 6061 alloy in order to provide better surface finish as well as high material removal rate. The selected cutting parameters were coolant employment (C), spindle speed (S), feed (F), and depth of cut (D). The experiments were conducted on L18 (21 × 33) orthogonal array. GRA has been used to find the best end milling process parameters with multiple performance characteristics.

3.0 METHODOLOGY

The present experimental investigation deals with the analysis of the experiment by the Full Factorial methodology. Based on the main effect's plots obtained through Full Factorial design, a total of 27 tests were carried out optimum level for MRR and cutting force were chosen from the three levels of cutting parameters considered. Machining parameters and their levels are shown in Table. The range of each parameter is set at three different levels, namely low, medium and high. Mathematical models were deduced by software design Expert in order to express the influence degree of the main cutting variables such as cutting speed, feed rate and depth of cut on cutting force components experiments with combination of different cutting parameters were randomly repeated. The 33= 27 experiments of settings were done to analyze the response that is the Cutting force and Material removal rate.

Fig 3.1 Milling Machine

3.5 Program Used For Machining

MAIN PROGRAM:

G17G9 :G75X0Y0Z0: M03S796: G00G90G54X-24.5Y-24.5: G00Z15:G01Z0F50: M08

L15P2

G00Z10: G75X0Y0Z0: M05M09M30

SUB PROGRAM:

G90X-24.5Y-24.5:G90X-24.5Y24.5; G90X24.5Y24.5;G90X24.5Y-24.5;G90X-24.5Y-24.5

G90X-9.5Y-9.5;G90X-9.5Y9.5;G90X9.5Y9.5;G90X9.5Y-9.5;G90X-9.5Y-9.5;G90X-3Y-3

G90X-3Y3;G90X3Y3;G90X3Y-3;G90X-3Y-3

3.9 Modeling of Cutting Tool

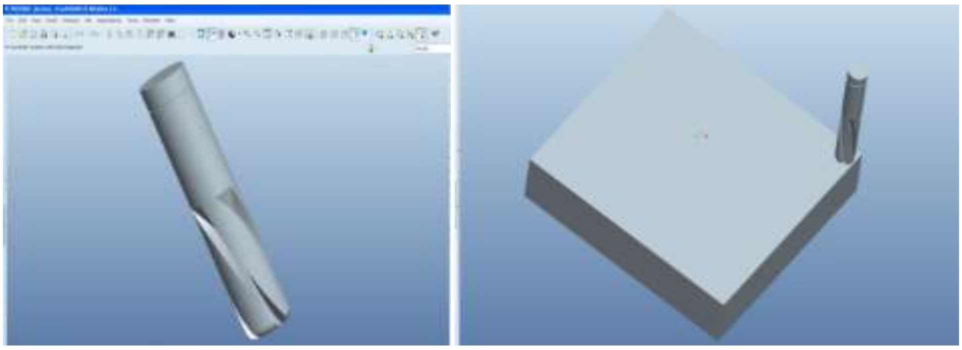


Fig 3.5 Model of Cutting Tool Assembly Of Cutting Tool and Work piece

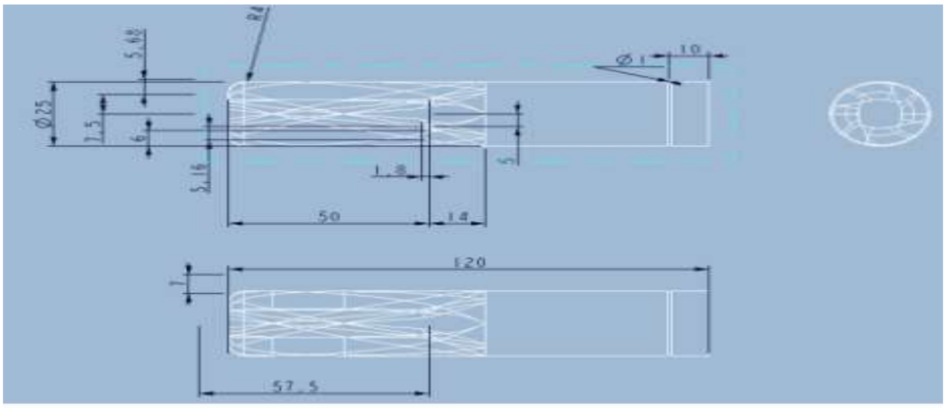


Fig 3.7 Cutting Tool geometrical view

EN-31 material ; The work piece material used is EN-31 Steel belongs to steel alloy of 50mm long 50mm breadth and 15mm thickness in the form of plates. The EN-31 defined a number of Emergency Number Steel alloy standards with a numbering scheme for easy reference and are mentioned them in the form of grades. In the present experiment the material used isEN-31 Steel, which is a Steel alloy. EN-31 Steel alloy consisting of 1.08% of carbon, 0.25% of silicon, 0.53% of manganese, 0.015% sulphur, 0.022% phosphorus, 0.33% of nickel, 1.46% of chromium, and 0.06% of molybdenum.

SS 304 material;Essentially non-magnetic, becomes slightly magnetic when cold worked, it has excellent corrosion and forming characteristics and highly ductile. This has corrosion resistance mostly with oxidizing acids and salt spray. This steel is widely used in petrochemical industries, diary, household and pharmaceutical purposes and cryogenic vessels, and as heat exchanger in air conditioning refrigeration factories.

Al 6061 Material ;An extensive experimental work in end milling of 6061 aluminum rectangular block was carried out to establish inter-relationships between machining performance measures and cutting parameters such as speed, feed and depth of cut. The machining performance measure under consideration is surface roughness.

3.11 Selection of Control Factors and Levels

A total of four process parameters with three levels are chosen as the control factors such that the levels are sufficiently far apart so that they cover wide range. The process parameter and their ranges are finalized using literature, books and machine operator's experience. The four control factors selected are spindle speed (A), feed rate (B), depth of cut(C) and coolant flow (D). EN-31 Steel alloy work pieces are used in experimentation. The machining is performed individually depending upon the lubricant conditions. The control levels and their alternative levels are listed in table

Feed – 200mm/min, 300mm/min, 400mm/min

Cutting speed – 2000rpm, 3000rpm, 3500rpm,

Depth of cut – 0.2mm, 0.3mm, 0.4mm

3.12 Selection of Orthogonal Array

Selection of particular orthogonal array from the standard O.A depends on the number of factors, levels of each factor and the total degrees of freedom. Number of control factors = 4 Number of levels for each control factors = 3.Total degrees of freedom of factors = 4x (3-1) = 8.Number of experiments

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to be conducted =9 Based on these values and the required minimum number of experiments to be conducted 9, the nearest Orthogonal Array fulfilling this condition is L9

Table 3.7 Standard L9 (3, 4) Orthogonal Array Experiment

Experiment No.	Control Factors			
	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

According to Taguchi's orthogonal array theory L9 orthogonal array is adopted for the whole experimentation for turning operation of SS 304 graded steel. In L9 orthogonal array, 9 experimental runs are conducted and the corresponding out puts is evaluated by Taguchi optimization technique. Here, Tool wears and means of surface roughness are measured by above said instruments and these values are taken out put responses in Taguchi optimization method.

Sl. no.	Cutting speed	Feed	Depth of cut
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

Here, the process variables are cutting speed, feed rate and depth of cut. These are the input parameters for the Taguchi optimization. So, nine experiments are carried out as per this orthogonal array and corresponding output data are recorded serially. The surface roughness was measured thrice times at different parts of the surface of work piece and then calculate the mean of those value.

Fig 3.8 CNC milling machine

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A comprehensive and in-depth review on optimization of different process parameters were carried out using different optimization tools. Milling machine is superior to other machine as regards accuracy and better surface finish. Every manufacturing industry is trying to achieve the high-quality products in a very short period of time with less input. So, process parameters are required to be optimizing for required quality parameters.

Cutter dia = 25R5 Width of Work piece = 75mm

No of Teeth on cutter = 4 = nc

Depth of Cut = d = 0.2mm Width of Cut = b = 5mm

Width of chip = bc = 5mm V = Cutting Velocity

rt = Chip Thickness Ratio rt = $t\ tc = vc$

$v = lc\ l$

LC = Length of Chip = 7mm

L = Uncut Chip Length = 75mm

$\propto$ = Rake Angle = 20°

β = Friction Angle = 40

∅ = Shear Angle Speeds (rpm) Feed (mm/min)

1. 3000 200
2. 2500 300
3. 2000 400

4.0 RESULTS AND DISCUSSIONS

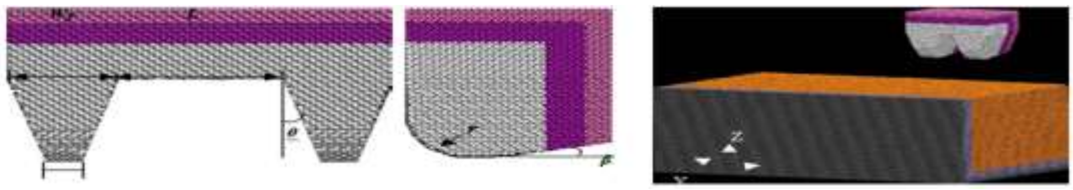
The milling operations are carried out on a CNC milling. The machining tests are conducted under the different conditions of Cutting speed, Feed rate, Depth of cut and coolant flow. The experiments are conducted at Government Polytechnic Thane and the machine tool used is HAAS CNC vertical milling machine.

EN-31 Steel alloy pieces of 45mmX45mmX15mm are prepared for conducting the experiment. Using different levels of the process parameters the specimens have been machined accordingly, depending upon speed, feed depth of cut and coolant flow conditions. Then surface roughness is measured precisely with the help of a pertho meter Optimization of surface roughness is carried out using Taguchi method. Confirmatory tests have also been conducted to validate optimal results.

Table 4.1 Operational variables and their levels in face diamond turning trials.

		No. of cut	**Depth of cut (nm)**	**Spindle speed (rpm)**	**Radius of start point (mm)**	**feed rate**
	1st	100	12	23.0	0.02890	9
	2nd	200	12	22.5	0.02827	9

section A	3rd	300	12	22.0	0.02765	9
	4th	400	12	21.5	0.02709	9
	4th	500	12	21.0	0.02639	9
	5th	100	12	19.0	0.11938	9
section B	6th	200	60	18.5	0.11624	9
	7th	300	60	18.0	0.11310	9
	8th	400	60	17.5	0.10996	9
	9th	500	60	17.0	0.10681	9
	10th	100	60	15.5	0.18850	9
section C	11th	200	120	15.0	0.18221	9
	12th	300	120	14.5	0.17593	9
	13th	400	120	14.0	0.17593	9
	14th	500	120	13.5	0.16965	9
	15th	100	120	13.0	0.016336	9



Molecular dynamics simulation model. (a) Front view of the multi-tip tool model; (b) right hand end elevation of the multi-tip tool model; and (c) nanometric cutting model

4.3 Nanostructures formed under different cutting conditions

As shown in figure the surface roughness S_a of the copper substrate was 1.85 nm prepared by the face diamond turning. The surface was then machined by the Nano scale multi-tip tool. The SEM images of machined nano-grooves under different depths of cut are shown in figure 4. In general, the periodic nanostructures pre-fabricated on the diamond tool tip were successfully replicated on the copper surface when the depths of cut of 100 nm and 200 nm were used. As shown in figure the measured bottom widths of the nano-grooves generated under the depth of cut 100 nm are ranged from 142.3 nm to 150.2 nm, which are slightly less than the tool tip width of 152.9 nm. The deviation is mainly due to the elastic recovery of the work material after the tool tip released from the surface [Moreover, the surface roughness S_a of the region between each cutting pass was found to be slightly increased to 2.50 nm (as shown in figure which is mainly caused by the material squeezed from the adjacent cutting passes. The form accuracy and integrity of the machined nano-grooves were found to be degraded with the increase of depth of cut. Visible side burrs were observed when the depth of cut was equal or larger than 300 nm Structure damage was found when a depth of cut of 400 nm was used. The results indicate that there exists an upper limit of depth of cut when machining Nano-grooves using Nano scale multi-tip diamond tools.

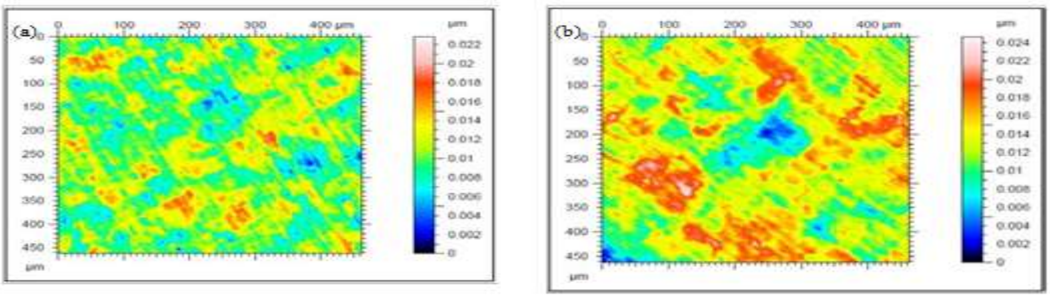


Fig 4.2 The surface roughness of workpiece (a) before nanoscale multi-tip tool cutting, and (b) after

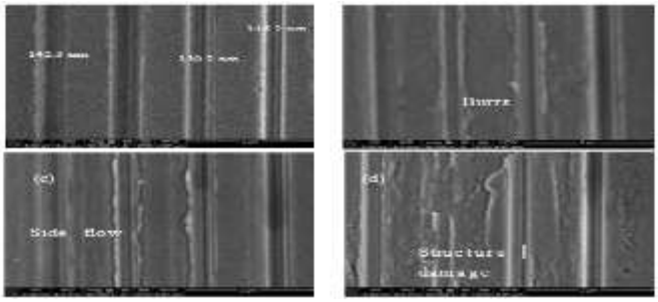
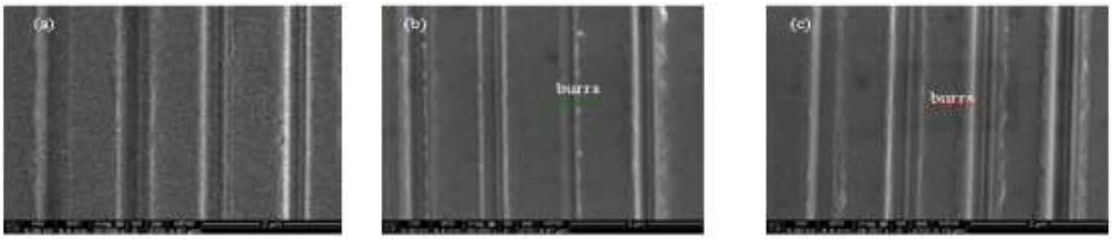


Fig 4.3 SEM images of Nano-grooves machined using different depth of cut. (a) 100 nm; (b) 200 nm; (c) 300 nm; (d) 400 nm. (Spindle speed = 12 rpm, feed rate = 9 µm/re).

The SEM images of nanostructures machined at different spindle speeds are shown in figure 5 (depth of cut = 100 nm). The results show that the form accuracy of the machined nano-grooves degrades with the increase of the cutting speed. No visible defect was found in the case of spindle speed being 12 rpm and 60 rpm. However, side burrs were observed when the spindle speed increased to 120 rpm. A similar cutting speed effect was observed when a depth of cut of 200 nm was used Under a large depth of cut of 300 nm (figure), the increase of cutting speed finally resulted in a seriously structure damage. Therefore, it can be concluded that the burr and the structure damage are the two major types of machining defects when improper processing parameters are used in Nano scale multi-tip tool cutting. The atomistic insight into the work material behavior responsible for the formation of the machining defects will be discussed in the next section.

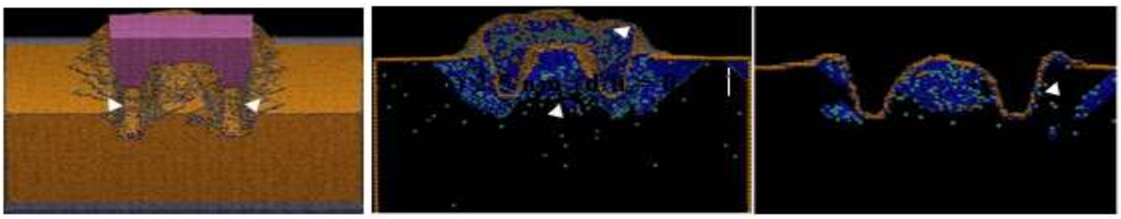


SEM images of nano-grooves machined under different spindle speeds. (a) 12 rpm; (b) 60 rpm (c) 120 rpm. (Depth of cut = 100 nm, feed rate = 9 µm/re).

4.4 Effect of depth of cut

The MD simulation results of machined nanostructures under different depths of cut (cutting speed = 200 m/s) are shown in figure 8. For better comparison, a ratio of depth of cut to tip height (d/h) was employed when comparing the simulation results with experimental results.

(a) 2.0nm (d/h = 0.46)



In the MD simulations, the form errors of the machined nanostructures in depth direction are all less than 5% for the cutting speed applied. Visible side burrs were observed only when the dislocation pile-ups took place. Thus it is predicted that, in nanoscale multi-tip tool cutting, there is a critical cutting speed below which the overlap effect can be ignored in machining nanostructures under a certain acceptable accuracy. nm.

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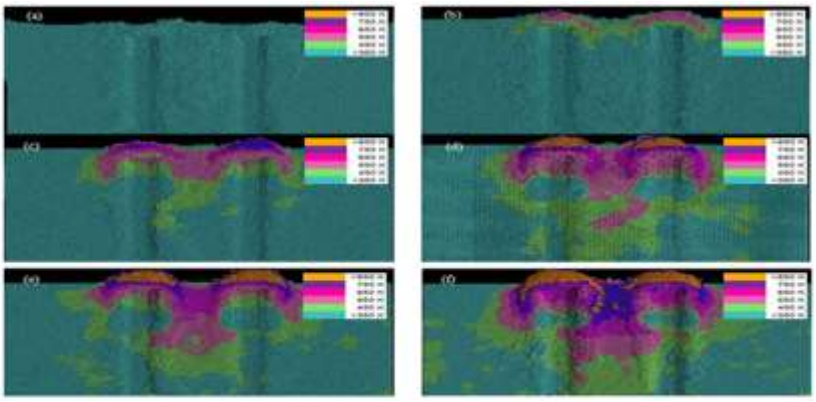

Fig 4.9 Temperature distribution under different cutting speeds. (a) 10 m/s; (b) 50 m/s; (c) 100 m/s; (d) 160 m/s; (e) 200 m/s; (f) 250 m/s

4.6 Observation of tool wear

The SEM images of the nanoscale multi-tip tool before and after cutting are shown in figure 11. Unlike the conventional single tip diamond tool cutting where the initial tool wear was mostly found at the clearance face near the tool cutting edges, the tool wear in the multi-tip tool cutting was found on both the clearance face and the sides of the tool tips after a cutting distance of 2.5 km. No visible wear marks were observed at the rake face of the tool tips. The measured tip distance enlarged from 706 nm to 743 nm because of the wear on the sides of the tool tips. The main reason of tool wear is that for multi-tip tool cutting, the nanostructures are formed synchronously within a single cutting pass. The sides of the tool tips are involved in the formation of nanostructures. The compressive stress produced at the sides of the tool tips increases in the friction between the tool tip and work piece, and thus results in the initiation of tool wear in this region.

Moreover, the tool wear is closely related to the local cutting temperature Figures 12 (a)-(c) show the temperature distributions of tool tips under different depths of cut. It is found that the temperature was uniformly distributed at the tool tip when a small depth of cut of 2.0 nm was used. However, a high local temperature (> 620 K) was generated both at the cutting edges and the side edges of the tool tips when cutting under a depth of cut of 3.0 nm. Similar results were observed when the depth of cut increased to 4.0 nm. This high local temperature would soften the C-C bonds strength and accelerate the tool wear process in these regions. In addition, it has been shown in figure 10 that a high cutting speed will apparently increase the cutting temperature at the cutting zone. It is thus anticipated that the tool wear rate will increase with the cutting speed as well.

Theoretically, the tool wear happens in force machining and the wear during the machining of a single part should not exceed the allowable limit The present study, for the first time, provides the significant information about the initial tool wear of the nanoscale multi-tip diamond tool during the nanometric cutting.

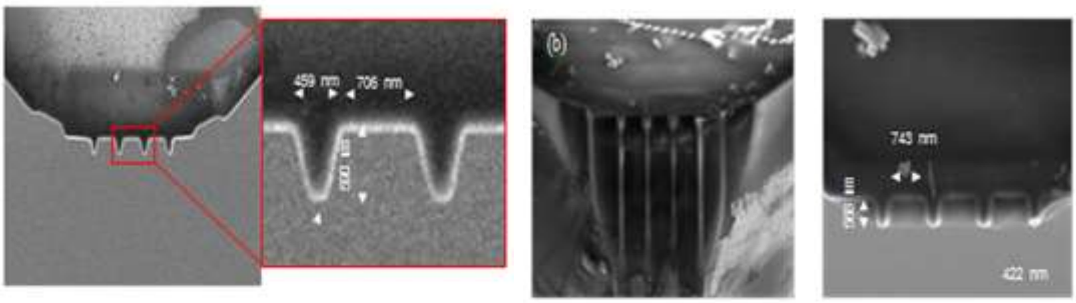

Table 4.3 : Experimental Data Related To Surface Roughness (Ra)

Exp No.	Surface Roughness(Ra)			S/N Ratio
	Traill	Trail2	Mean	
1	1.6559	2.3320	1.99395	-6.11735
2	2.2003	1.7485	1.9744	-5.96519
3	2.2804	3.0328	3.96835	-8.57275
4	0.6075	1.6260	1.11675	-1.77959
5	1.8958	2.1895	2.04265	-6.22627
6	0.7520	1.2829	1.01745	-0.43625
7	0.5510	1.2454	0.8982	0.32775
8	0.7768	0.7730	0.7749	2.21506
9	0.5074	0.6065	0.55695	5.04944

After determining the S/N ratio values the effect of each Machining parameter is separated based on S/N ratio at different levels and the values of S/N ratio for each level of the controllable parameters and the effect of parameter on response (Ra) in rank wise are summarized. Basically, large S/N ratio means it is close to good quality, thus, a higher value of the S/N ratio is desirable. the cutting parameters with the best level are spindle speed at level-3, feed at level-3 DOC at level-2 and coolent flow level The surface roughness (Ra) value obtained for these optimum control parameters is 0.55695µm

Table 4.4 : S/N ratio for each level of control parameters (Response based on S/N ratio)

Level	V (rpm)	F (mm/min)	t (mm)	Coolant flow
1	-6.88510	-2.52307	-1.44618	-2.43140
2	-2.81404	-3.32546	-0.89845	-2.02456
3	2.53075	1.31985	-4.82376	2.71243
Delta	9.41585	2.00561	3.92531	0.68787
Rank	1	3	2	4

the response graph for four factors and three levels. From the graphical representation the peak points are chosen as the optimum levels of machining parameters, such as level two of number of pass, level one of depth of cut, level three of spindle speed, level three of feed rate The curve showing larger amount of inclination is the most significant curve, while the curve being horizontal to the mean line has less significant effect over the surface roughness If the curve are not parallel and crosses each other, then a powerful interaction occurs and vice-versa the surface roughness is high at low speed and certainly decreasing from moderate cutting speed to high speed conditions.

H13 Results obtained against varying feed

Exp .No	Depth of cut (mm)	Force (N)	Power (KW)	Tool life (min)
1	0.5	196	85.45	1433.83
2	1	392	164	1828.81
3	1.5	784	314	2363

EN 31 Results obtained against varying feed

Exp .No	Depth of cut (mm)	Force (N)	Power (KW)	Tool life (min)
1	0.5	392	205.86	472.55

2	1	784	397.75	128.09
3	1.5	1176	565.06	72.96

SS 304 Results obtained against varying feed

Exp .No	Depth of cut (mm)	Force (N)	Power (KW)	Tool life (min)
1	0.5	784	36.15	210704.32
2	1	784	57.56	14658
3	1.5	784	76.47	2755.76

5.0 CONCLUSIONS

During the cutting process, the highest temperature is reached at the tool-to-work contact area. Three steps of optimal process parameters for tool life are provided: The ideal point is reached at 0.5 mm depth of cut, where the cutting force is 392N and the tool life is 472 minutes, by adjusting the depth of cut while maintaining the other two process parameters, namely speed and feed.

The optimal point is reached at 1.4mm/rev, where the cutting force is 784N and the tool life is 2363 minutes, by adjusting the feed rate while maintaining the other two process parameters constant.

The ideal point, where the cutting force is 784N and the tool life is 210704 min, is reached at 230 rpm by adjusting the speed while maintaining the other two parameters constant.

All four elements have been taken into consideration and are mostly responsible for the response. Using the Taguchi approach, the ideal combination of machining parameters has been discovered. Of all the factors taken into account, speed has the most impact on the workpiece's surface finish.The tauguchi technique was used in this experiment to determine the optimal speed, which is 1150 rpm. Likewise, 175 m/min and 1 mm, respectively, are the feed and depth of cut findings. Therefore, the parameters obtained are considered legitimate and fall within the range of EN31 machining standards. 20 liters per minute is the matching optimal coolant flow. When compared to the optimal values, the S/N ratio of the anticipated value and verification test values is valid. The verification test's S/N ratio value is determined to be within the projected range, meaning the work's goal has been fully achieved.

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