EVALUATION OF CHIP BREAKER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR DEGREE OF

Bachelor of Technology
in
Mechanical Engineering

By

NELSON TIRKEY
Roll No: 10503024

Department of Mechanical Engineering
National Institute of Technology
Rourkela

2009

EVALUATION OF CHIP BREAKER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR DEGREE OF

Bachelor of Technology
in
Mechanical Engineering

By

NELSON TIRKEY
Roll No: 10503024

Under the Guidance of
Prof. C.K. Biswas

Department of Mechanical Engineering
National Institute of Technology
Rourkela

2009

National Institute of Technology
ROURKELA

CERTIFICATE

This is to certify that the thesis entitled, "**EVALUATION OF CHIP BREAKER**" submitted by **Sri Nelson Tirkey** in partial fulfillment of the requirements for the award of Bachelor of Technology in **Mechanical Engineering** at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any Degree or Diploma.

Date:

Prof. C.K. BISWAS
Dept. of Mechanical Engg.
National Institute of Technology
Rourkela - 769008

ACKNOWLEDGEMENT

I avail this opportunity to extend my hearty indebtedness to my guide **Prof C.K. Biswas,** Mechanical Engineering Department, for his valuable guidance, constant encouragement and kind help at different stages for the execution of this dissertation work.

I also express my sincere gratitude to **Mr. Kunal Nayak** and **Mr.Biswanath Mukherjee** for extending his help in completing this project.

I take this opportunity to express my sincere thanks to my project guide for co-operation and to reach a satisfactory conclusion.

Nelson Tirkey
Roll No: 10503024
Mechanical Engineering
National Institute of Technology
Rourkela

CONTENTS

		Page No.
Abstract		i
List of figures		ii
List of Tables		iii
Chapter 1	**Introduction**	1
	Introduction	2
	1.1 Chip Breaker	3
	1.2 Classification of chip pattern	4
Chapter 2	**Brief Introduction of the project**	5
	2.1 Need and purpose of chip-breaking	6
Chapter 3	**Literature Review**	7
	3.1 Experimental studies on chip breaker	8
	3.2 Principles of chip breaking	9
Chapter 4	**Experimental work**	13
	Introduction	14
	4.1 Procedure	14
Chapter 5	**Results and discussion**	17
	Introduction	18
	5.1 Response surface methodology for ξ	19
	5.2 Response surface methodology for chip length	26
	5.3 Conclusion	35
References		36

ABSTRACT

Optimization of machining operations is one of the key requirements of today's automatic machines. In case of turning, unbroken chips pose a major hindrance during operation and hence appropriate control of the chip shape becomes a very important task for maintaining reliable machining process. The continuous chip generated during turning operation deteriorates the workpiece precision and causes safety hazards for the operator. In particular, effective chip control is necessary for a CNC machine or automatic production system because any failure in chip control can cause the lowering in productivity and the worsening in operation due to frequent stop. Chip control in turning is difficult in the case of mild steel because chips are continuous. Thus the development of a chip breaker for mild steel is an important subject for the automation of turning operations. In this study, the role of different parameters like speed, feed and depth of cut and chip breaker height and width are studied.

Response surface methodology was used to analyze the relationship between several explanatory variables and one or more response variables. The chips obtained were found to have greater thickness at low feed and depth of cut, and gradually decreased as feed and depth of cut increases. From the analysis of chip reduction coefficient ξ, lead to the conclusion that cutting speed and depth of cut are most significant factors along with their higher order terms.

List of Figures

Page No.

Fig.1.1 Classification of chip pattern (INFOS) 4

Fig. 3.1 Principles of self breaking of chips 10

Fig. 3.2 Principle of forced chip breaking 11

Fig. 3.3 Clamped type chip breakers 12

Fig .4.1 Heavy duty HMT lathe machine 15

Fig 4.2 Experimental set up (cutting tool with workpiece) 15

Fig. 5.1 Chips photograph for cutting speed 40 m/min 18

Fig. 5.2 Chips photograph for cutting speed 50 m/min 18

Fig. 5.3 Chips photograph for cutting speed 60 m/min 19

Fig 5.4 Histograms of the residuals for ξ 24

Fig 5.5 Normal probability plot of the residuals for ξ 24

Fig 5.6 Residuals vs the order of the data for ξ 25

Fig. 5.7 Residuals vs the fitted values for ξ 25

Fig 5.8 Histograms of the residuals for chip length 31

Fig 5.9 Normal probability plot of the residuals for chip length 31

Fig 5.10 Residuals vs the order of the data for chip length 32

Fig. 5.11 Residuals vs the fitted values for chip length 32

List of Tables

Page no.

Table 1 Experimental condition 14

Table 2 Observation table for the experiment 15

Table 3 Analysis of Variance for ξ 21

Table 4 Estimated Regression Coefficients for ξ
(The analysis was done using coded units.) 22

Table 5 Unusual observation for ξ 23

Table 6 Analysis of Variance for chip length 27

Table 7 Estimated Regression Coefficients for chip length 28
(The analysis was done using coded units.)

Table 8 Unusual observation for chip length 29

Table 9 Estimated Regression Coefficients for ξ and chip length
using data in uncoded units 33

CHAPTER 1

Introduction

INTRODUCTION :

Machining is a process of shaping by the removal of material which results in chips. The geometrical and metallurgical characteristics of these chips are very representative of the performances of the process. Indeed, they bear witness to most of the physical and thermal phenomena occurring during the machining.

Present day manufacturing methods require maximization in productivity. With the introduction of Computer Integrated Manufacturing (CIM) system and Flexible Manufacturing System (FMS) have led to maximization in productivity. Seeing the present demanding situation, the quality of cutting tools has been improved continuously for better cutting techniques.

However, numerous chips are being generated in short time in these methods which requires effective control of long continuous chips which is one of the most important factors for work performance. When the chips are out of control, it may lead to system failure which directly affects productivity.

The chip shape generated in cutting processing is closely related to product productivity. If an incorrect chip shape is generated, time and money is lost from safety hazards to the operator, damage of production tools and workpiece surface, not to mention the loss in productivity due to the frequent stopping of the production machine.

Failure in chip control is closely related to surface roughness of the workpiece, precision of product, and wear of tool, etc. However, chip breaker performance testing requires significant time and effort. In addition, developing new cutting inserts necessitates forming, sintering, grinding, and coating processes, extends developing time and involves expensive research.

Chip control is essential to ensure reliable operation in automated machining systems. Effective chip control requires predictability of chip form/chip breakability for a given set of input machining conditions. But, it is difficult to predict the chip formation process due to the complex mechanism of chip formation under various combinations of machining conditions with numerous interacting process parameters involved.

1.1 Chip breaker

A chip breaker is the tool which has a groove or an obstacle placed on the incline face of the tool. A chip breaker can be used for increasing chip breakability which results in efficient chip control and improved productivity. It also decreases cutting resistance, and gives a better surface finish to the workpiece. This also leads to a greater tool life. A chip breaker is usually used for improving chip breakability by decreasing the chip radius. The chip breaker pattern affects chip breakability.

The principle of chip breaker is that fracture is generated by the force and moment acting on chip surface.

The process of metal cutting by a single point cutting tool generates narrow and long chips that lead to problems such as difficulty in chip handling, surface damage of products, tangling together and safety hazards for the operator. Therefore, it is necessary to cut chips to the appropriate size.

Chips generated during metal cutting usually curl, and may strike against workpiece or tool, leading to chip breaking. Patterns and sizes of broken chips are different depending on deformation mechanism and collision location. The generated chip makes continuous curling and it is known that chip breakability enlarges when we reduce the up curling radius and down curling radius of a chip clearance that is formed at this time.

In determination of chip pattern, it is to be ensured that appropriate external force is applied to the chip, as it increases the fracture strain of the chip and decreases the radius of the chip.

Parameters like depth, land, breadth, radius of the chip breaker play a significant role in determining the chip breakability. These factors lead to better designs of chip breaker.

Indeed, much research has been accomplished, but it is difficult to break chips in the finishing of mild steel. The type of chip breakers available fall into categories of grooved and attached. From, the view point of tool strength, an attached chip breaker is better than grooved one.

1.2 Classification of chip pattern

Chip pattern has been classified by CIRP and INFOS, but each classification is very similar. Chip pattern classified by INFOS is illustrated in fig. 1

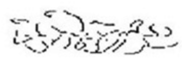
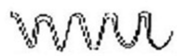
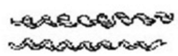
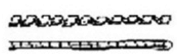
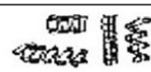
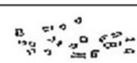
1		ribbon chips
2		tangled chips
3		corkscrew chips
4		helical chips
5		long tubular chips
6		short tubular chips
7		spiral tubular chips
8		spiral chips
9		long comma chips
10		short comma chips

Fig.1 Classification of chip pattern (INFOS)

CHAPTER 2

BRIEF INTRODUCTION OF THE PROJECT

2.1 Need and purpose of chip-breaking

Continuous machining like turning of ductile metals, produce continuous chips, which leads to their handling and disposal problems. The problems become acute when ductile but strong metals like steels are machined at high cutting velocity for high MRR by flat rake face type carbide or ceramic inserts. The sharp edged hot continuous chip that comes out at very high speed

- becomes dangerous to the operator and the other people working in the vicinity
- creates difficulties in chip disposal
- may impair the finished surface by entangling with the rotating job

Therefore it is essentially needed to break such continuous chips into small regular pieces for

- safety of the working people
- prevention of damage of the product
- Easy collection and disposal of chips.

Chip breaking is done in proper way also for the additional purpose of improving machinability by reducing the chip-tool contact area, cutting forces and crater wear of the cutting tool.

Therefore the purpose of this study is to solve the problems of continuous chip and construct the basis of improved factory automation by using chip breakers of the attached obstruction type, which represents a new concept in chip breaking.

In this project, parameters like cutting speed, feed, depth of cut, height and width of chip breaker will be studied and how they effect the chip breakability, so that better control of chip can be done.

CHAPTER 3

LITERATURE REVIEW

3.1 EXPERIMENTAL STUDIES ON CHIP BREAKER:

J.D.Kim et.al. [1], has laid emphasis on use of attached type chip breakers from the view point of tool strength and also the characteristics of chip flow is the function of nose radius, cutting speed, inclined angle and curvature of workpiece. It also classified the chips into good breaking region, transient region and unbroken chip region on basis of broken chips obtained. It also showed that the thickness of chip is directly proportional to feed rate and inversely proportional to shear angle. It also clearly stated that low and medium cutting speeds lead to good breaking conditions whereas at high cutting speeds, a side curls chip changes to snarled chip.

R.M.D. Mesquita et.al [2], devised a method for the prediction of cutting forces when machining with cutting tools with chip breakers, that can be used to predict the cutting forces for a wide range of cutting conditions (feed and depth of cut), taking into account the effective side-rake angle and the indentation force components. The effective side-rake angle must be established from the geometry of the chip breaker. The indentation force is dependent on the depth of cut.

Hong-Gyoo Kim et.al [3], established the fact that as the chip breaker depth increases, and the width decreases, performance of chip breaking was excellent at the finishing area. However, the chip breakability was excellent at the roughing area as the depth decreased and the width increased.

N.S.Das et.al [4] showed that the breaking strain in the chip is the most important factor on which chip breaking depends and a method was suggested for determining chip breaker distance for any given feed and chip breaker height for effective chip breaking. It also showcased that the chip breaking criterion is based neither on specific cutting energy nor on material damage which can be taken as adequate criterion for chip breaking.

K.P.Maity et.al. [5] showed that the optimum positions of the chip-breaker is around 13- 14 times the uncut chip-thickness, with a step-height equal to four times the uncut chip-thickness, since the cutting forces become minimum at these positions. There is no chip-breaking effect when the chip-breaker position is more than 28.8 times the uncut chip-thickness. The minimum position of the chip-breaker is around 17 times the uncut chip-thickness for all possible modes of deformation.

M. Rahman et.al [6], has dealt with a three-dimensional model of chip flow, chip curl and chip breaking, taking into account the geometrical, the kinetic, as well as the mechanical features. For all these, a set of equivalent characteristic parameters was defined and a relationship was developed between these and the actual machining parameters.

G. Sutter et.al [7], presented a 'dimensional analysis' of the root chip in orthogonal cutting. Different models of the chip length contact were validated at the sight of experimental measurements. The chip thickness ratio tends to 1 when the uncut chip thickness increases. The principle of minimum rate of work was confirmed with the effect of the cutting speed on the shear angle.

3.2 Principles of chip-breaking

The principles and methods of chip breaking are generally classified as follows:

- **Self breaking**: This is accomplished without using a separate chip-breaker either as an attachment or an additional geometrical modification of the tool.
- **Forced chip breaking** by additional tool geometrical features or devices

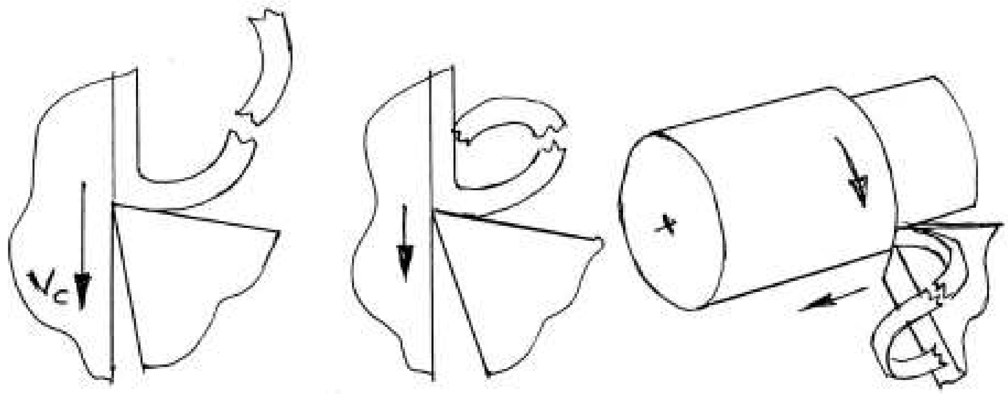
(a) Self breaking of chips

Ductile chips usually become curled or tend to curl (like clock spring) even in machining by tools with flat rake surface due to unequal speed of flow of the chip at its free and generated (rubbed) surfaces and unequal temperature and cooling rate at those two surfaces. With the increase in cutting velocity and rake angle (positive) the radius of curvature increases, which is more dangerous. In case of oblique cutting due to presence of inclination angle, restricted cutting effect etc. the curled chips deviate laterally resulting helical coiling of the chips.

The curled chips may self break:

- By natural fracturing of the strain hardened outgoing chip after sufficient cooling and spring back as indicated in Fig.3.1 (a). This kind of chip breaking is generally observed under the condition close to that which favors formation of jointed or segmented chips.

- By striking against the cutting surface of the job, as shown in Fig. 3.1 (b), mostly under pure orthogonal cutting.
- By striking against the tool flank after each half to full turn as indicated in Fig 3.1(c).



(a) Natural (b) striking on job (c) striking at tool flank

Fig. 3.1 Principles of self breaking of chips.

(b) Forced chip-breaking

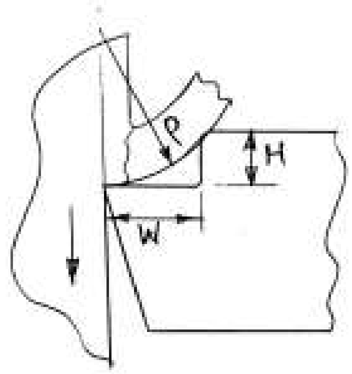
The hot continuous chip becomes hard and brittle at a distance from its origin due to work hardening and cooling. If the running chip does not become enough curled and work hardened, it may not break. In that case the running chip is forced to bend or closely curl so that it breaks into pieces at regular intervals. Such broken chips are of regular size and shape depending upon the configuration of the chip breaker.

Chip breakers are basically of two types:

- In-built type
- Clamped or attachment type

In-built breakers are in the form of step or groove at the rake surface near the cutting edges of the tools. Such chip breakers are provided either

- After their manufacture – in case of HSS tools like drills, milling cutters, broaches etc and brazed type carbide inserts.
- During their manufacture by powder metallurgical process – e.g., throw away type inserts of carbides, ceramics and cermets.



W = width, **H** = height, **β** = shear angle

Fig. 3.2 Principle of forced chip breaking.

The unique characteristics of in-built chip breakers are:

- The outer end of the step or groove acts as the heel that forcibly bends and fractures the running chip
- Simple in configuration, easy manufacture and inexpensive
- The geometry of the chip-breaking features are fixed once made (i.e., cannot be controlled)
- Effective only for fixed range of speed and feed for any given tool-work combination.

Some commonly used step type chip breakers:

a. Parallel step
b. Angular step; positive and negative type
c. Parallel step with nose radius – for heavy cuts

Groove type in-built chip breaker may be of

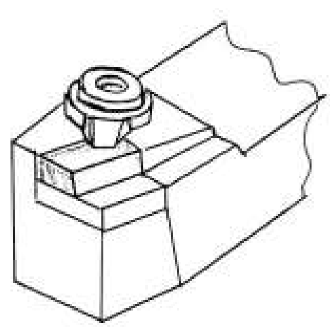
- Circular groove
- Tilted V groove

(c) Clamped type chip-breaker

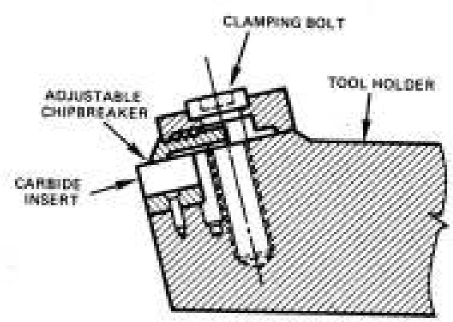
Clamped type chip breakers work basically in the principle of stepped type chip-breaker but have the provision of varying the width of the step and / or the angle of the heel.

Fig. 3.3 schematically shows three such chip breakers of common use:

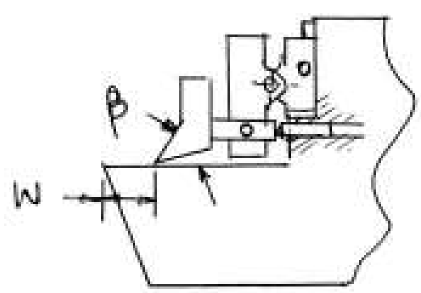
a. With fixed distance and angle of the additional strip – effective only for a limited domain of parametric combination
b. With variable width (W) only – little versatile
c. With variable width (W), height (H) and angle (β) – quite versatile but less rugged and more expensive.



(a) Fixed geometry



(b) variable width



(c) Variable width and angle

Fig. 3.3 Clamped type chip breakers

CHAPTER 4

EXPERIMENTAL WORK

Introduction

This section contains the procedure adopted for the experiment. The calculations of parameters i.e., chip thickness and length was carried out with the help of tool makers microscope. The analysis of the results obtained was carried out through Response surface methodology(RSM) using Minitab software.

4.1 Procedure:

For the experiment, a heavy duty HMT lathe was used as shown in fig.4.1. A cutting test was performed to calculate the chip length and thickness. For this, three tools of specific dimension were taken and chip breakers were welded by TIG welding at widths of 3, 4 and 5 mm as per the requirements of experiment. The workpiece used was mild steel shaft of 52 mm diameter. The workpiece was fitted between the chuck and tail stock and centering was done to avoid any vibrations during experiment.

The height of chip breaker was adjusted as per the experiment requirements by grinding. Then the tool was fitted in the tool post as shown in fig. 4.2. The experiment conditions were taken as shown in Table 1.

Each experiment was performed with continuous straight turning with coolant on. The experiments were carried out as per Table 2 by varying speed, feed, and depth of cut. The same procedure was adopted using the other two tools to get the relevant data.

Fig .4.1 Heavy duty HMT lathe machine

Fig 4.2 Experimental set up (cutting tool with workpiece)

Table 1: Experimental condition

Condition	**Units**	**Value**
Cutting speed	m/min	40, 50, 60
Depth of cut	mm	0.1, 0.3, 0.5
Feed	mm/rev	0.1, 0.3, 0.5
Cutting condition		Flood cooling
Tool		Relief angle 5° Rake angle 5° Side rake angle 0°
Tool material		HSS
Workpiece material		Mild steel

Table 2: Observation table for the experiment

Run Order	Machine parameters Speed (s)	Feed (f)	Depth of cut (d)	Chip breaker Height (H)	Width (W)	Chip parameters Chip Length (L)	chip thickness	Chip reduction coefficient (ξ)
	m/min	mm/rev	mm	mm	mm	mm	mm	
1	40	0.1	0.1	0.3	5	17.857	0.162	1.620
2	60	0.1	0.1	0.3	3	33.203	0.210	2.100
3	50	0.3	0.1	0.45	4	10.537	0.211	2.110
4	60	0.1	0.1	0.6	5	16.625	0.233	2.330
5	60	0.5	0.1	0.6	3	43.253	0.241	2.410
6	60	0.5	0.1	0.3	5	57.925	0.243	2.430
7	40	0.1	0.1	0.6	3	49.699	0.210	2.100
8	40	0.5	0.1	0.6	5	49.009	0.152	1.520
9	40	0.5	0.1	0.3	3	69.931	0.220	2.200
10	50	0.3	0.3	0.45	4	37.385	0.450	1.500
11	50	0.3	0.3	0.45	4	24.957	0.456	1.520
12	50	0.1	0.3	0.45	4	29.518	0.486	1.620
13	50	0.3	0.3	0.3	4	13.289	0.408	1.360
14	50	0.3	0.3	0.45	4	41.569	0.423	1.410
15	50	0.3	0.3	0.45	4	90.955	0.438	1.460
16	60	0.3	0.3	0.45	4	79.168	0.462	1.540
17	50	0.5	0.3	0.45	4	75.837	0.468	1.560
18	50	0.3	0.3	0.45	3	48.553	0.480	1.600
19	50	0.3	0.3	0.45	5	90.854	0.483	1.610
20	50	0.3	0.3	0.45	4	20.508	0.489	1.630
21	40	0.3	0.3	0.45	4	6.013	0.312	1.040
22	50	0.3	0.3	0.45	4	37.162	0.408	1.360
23	50	0.3	0.3	0.6	4	68.112	0.522	1.740
24	40	0.5	0.5	0.3	5	69.429	0.685	1.370
25	60	0.1	0.5	0.3	5	37.966	0.670	1.340
26	50	0.3	0.5	0.45	4	26.876	0.670	1.340
27	40	0.1	0.5	0.3	3	71.314	0.685	1.370
28	40	0.1	0.5	0.6	5	42.851	0.610	1.220
29	40	0.5	0.5	0.6	3	57.019	0.625	1.250
30	60	0.1	0.5	0.6	3	60.277	0.620	1.240
31	60	0.5	0.5	0.3	3	83.889	0.610	1.220
32	60	0.5	0.5	0.6	5	23.112	0.810	1.620

CHAPTER 5

RESULTS AND DISCUSSIONS

Introduction:

The photographs of chip obtained are presented in figures 5.1, 5.2 and 5.3 for the cutting speed 40, 50 and 60 m/min, respectively. These samples of chips are shown in the figures with increasing feed and depth of cut as x axis and y axis, respectively.

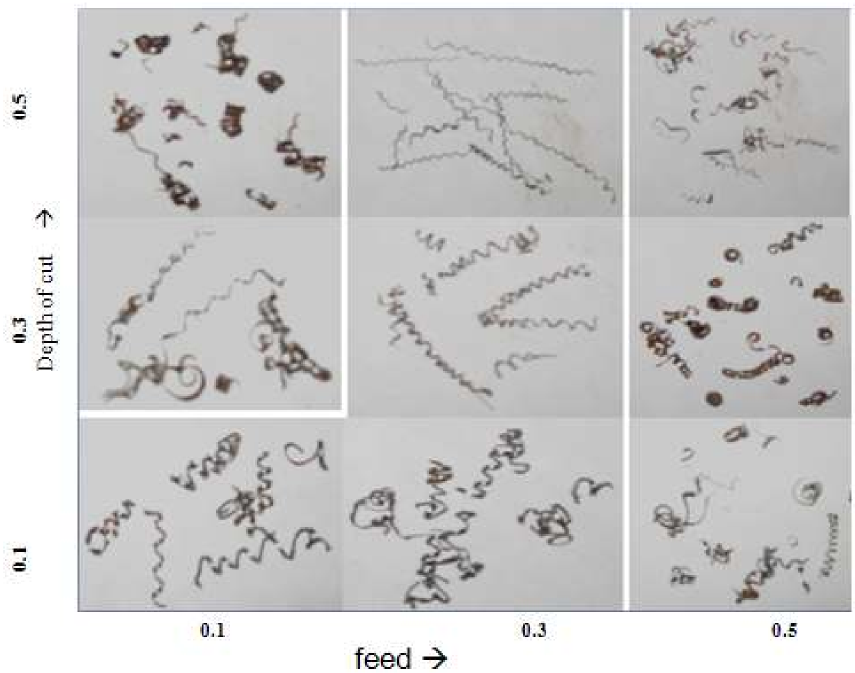


Fig. 5.1 Chips photograph for speed = 40 m/min

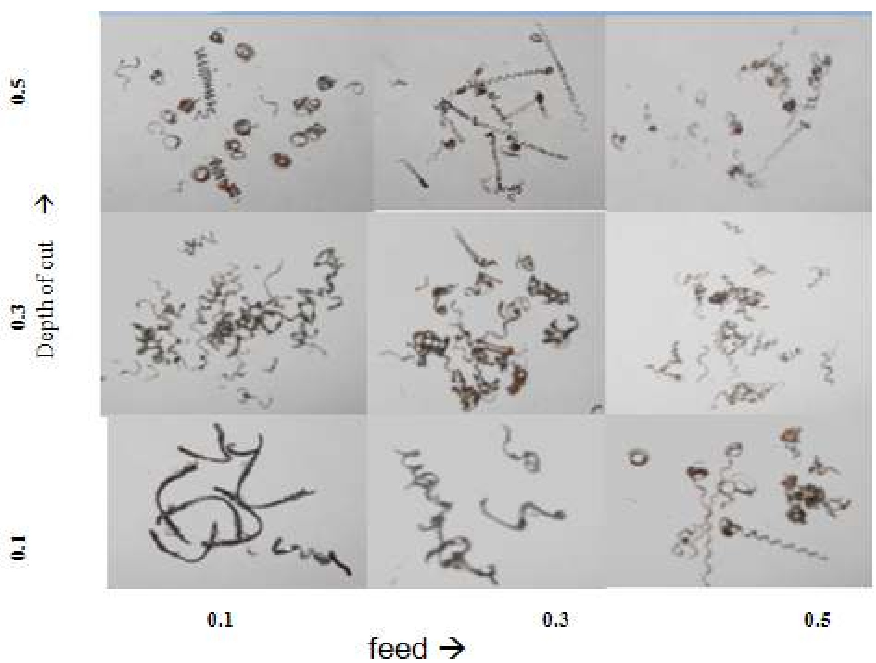


Fig. 5.2 Chips photograph for speed = 50 m/min

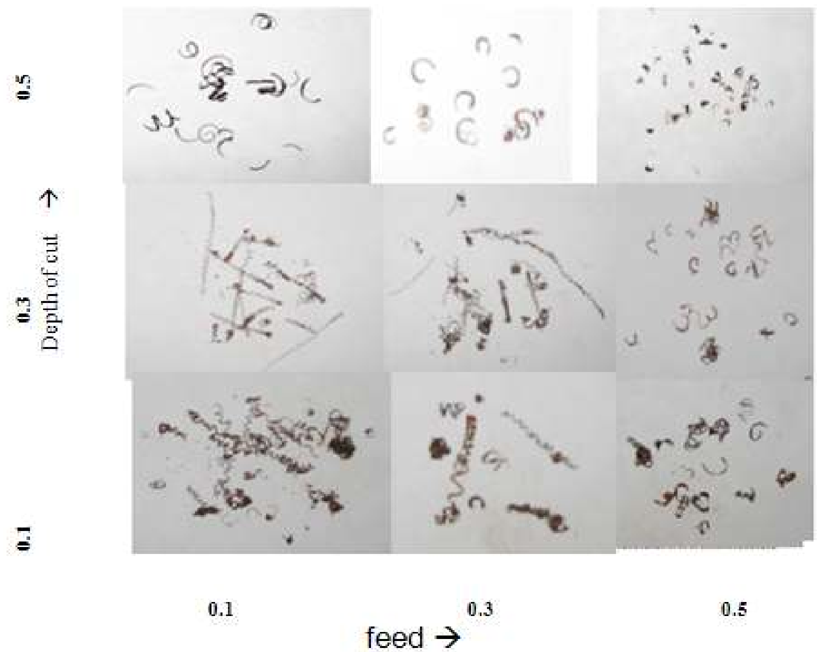


Fig. 5.3 Chips photograph for speed = 60 m/min

5.1 Response Surface Methodology (RSM) for ξ

The experimental results were analyzed by RSM using Minitab software. RSM explores the relationship between several explanatory variables and one or more response variables. The main idea of RSM is to use a set of designed experiments to obtain an optimal response.

Using this method, various tables were analyzed to see the relationship of different variables and their significance.

From table 3, analyzing of variance shows that the terms having the values of probability less than 0.05 are significant. All the linear, square and interaction terms are significant for the model. The value of lack of fit is more than 0.05, which asserts that that the model is adequate.

Table 4 of estimated regression coefficients using coded units has a few terms having probabilities above 0.05.These terms include H, W, H*H, W*W, s*f which are insignificant in determination of model analysis. However, the cutting speed, s and depth of cut, d are significant along with their higher order terms.

In table 5 of unusual observation of ξ, three values show a large standardized residual unusual observation implying that the observations are not correct and are to be repeated.

In fig. 5.4, the histogram of residuals is shown that has a normal distribution with a few observations deviating from the normal curve. If this assumption is valid, a histogram plot of the residuals should look like a sample form a normal distribution.

In fig. 5.5, the graph of normal probability plot vs residuals shows that most of the points are near the line implying the residual is normal. Observations showing standardized residual greater than 2 are to be investigated and may be the experiments repeated to get the adequate model. A normality probability plot of residuals can similarly be conducted. If the underlying error distribution is normal, the plot will resemble a straight line and expects considerable departures from a normality appearance when the sample size is small. Commonly a residual plot will show one point that is much larger or smaller than the others. These residuals are typically called out liner. One or more outliner can distort the analysis. Frequently, outliners are caused by the erroneous recording of information. If this is not the case, further analysis should be conducted. This data point may give additional insight to what should be done to improve a process dramatically.

For a good model fit this plot should show a random scatter and have no pattern. Common description includes the following

- Outliner, which appear as appoint hat are either much higher or lower than normal residual value. These points should be investigated. Perhaps some one a number recorded wrong. Perhaps evaluation of this sample provides additional knowledge that leads to major process equipment break through.
- Non constant variance, where the difference between the lowest and highest residual values either increases or decreases for an increase in the fitted values. A measurement instruction could cause this where error is proportional to the measured value.
- Poor model fit, where for example, residual values seem to increase and then decrease with an increase in the fitted value for the described situation, a quadratic model might possibly be a better fit than a linear model.

In fig. 5.6, the graph of residuals vs fitted values, the ξ values which are greater than 2 are insignificant.

In fig. 5.7, we check the correlation between residuals by plotting residuals in sequence and the graph of residual vs order of data shows the standardized residual for the run order of experiment. This implies that the residuals are random in nature and don't exhibit any pattern with run order.

Table 3 Analysis of Variance for ξ

Source		DF	Seq SS	Adj SS	Adj MS	F	P
Regression		20	4.15682	4.15682	0.207841	15.42	0.000
	Linear	5	3.00806	3.00806	0.601611	44.63	0.000
	Square	5	0.49192	0.49192	0.098384	7.30	0.003
	Interaction	10	0.65685	0.65685	0.065685	4.87	0.008
Residual	Error	11	0.14826	0.14826	0.013479		
	Lack-of-Fit	6	0.10406	0.10406	0.017344	1.96	0.238
	Pure Error	5	0.04420	0.04420	0.008840		
Total		31	4.30509				

Table 4 Estimated Regression Coefficients for ξ (The analysis was done using coded units.)

Term	Coefficient	SE Coefficient	T statistics	P value
Constant	1.49673	0.03318	45.111	0.000
s	0.14111	0.02736	5.157	0.000
f	0.03556	0.02736	1.299	0.220*
d	-0.38056	0.02736	-13.907	0.000
H	0.02333	0.02736	0.853	0.412*
W	-0.02389	0.02736	-0.873	0.401*
s*s	-0.21928	0.07401	-2.963	0.013
f*f	0.08072	0.07401	1.091	0.299*
d*d	0.21572	0.07401	2.915	0.014
H*H	0.04072	0.07401	0.550	0.593*
W*W	0.09572	0.07401	1.293	0.222*
s*f	0.04000	0.02902	1.378	0.196*
s*d	-0.10125	0.02902	-3.488	0.005
s*H	0.06125	0.02902	2.110	0.059*
s*W	0.12125	0.02902	4.178	0.002
f*d	-0.00750	0.02902	-0.258	0.801*
f*H	-0.05500	0.02902	-1.895	0.085*
f*W	0.01000	0.02902	0.345	0.737*
d*H	0.00125	0.02902	0.043	0.966*
d*W	0.08625	0.02902	2.972	0.013
H*W	-0.01125	0.02902	-0.388	0.706*
S = 0.1161	R-Sq = 96.6%		R-Sq(adj) = 90.3%	
* insignificant terms				

Table 5 Unusual observation for ξ

Observation	Std Order	ξ	Fit	SE Fit	Residual	Std Residual	remark
1	1	1.620	1.599	0.114	0.021	0.94	
2	2	2.100	2.099	0.114	0.001	0.02	
3	3	2.110	2.093	0.083	0.017	0.21	
4	4	2.330	2.378	0.114	-0.048	-2.21	R
5	5	2.410	2.435	0.114	-0.025	-1.13	
6	6	2.430	2.420	0.114	0.010	0.44	
7	7	2.100	2.114	0.114	-0.014	-0.64	
8	8	1.520	1.525	0.114	-0.005	-0.22	
9	9	2.200	2.156	0.114	0.044	2.02	R
10	10	1.500	1.497	0.033	0.003	0.03	
11	11	1.520	1.497	0.033	0.023	0.21	
12	12	1.620	1.542	0.083	0.078	0.96	
13	13	1.360	1.514	0.083	-0.154	-1.89	
14	14	1.410	1.497	0.033	-0.087	-0.78	
15	15	1.460	1.497	0.033	-0.037	-0.33	
16	16	1.540	1.419	0.083	0.121	1.49	
17	17	1.560	1.613	0.083	-0.053	-0.65	
18	18	1.600	1.616	0.083	-0.016	-0.20	
19	19	1.610	1.569	0.083	0.041	0.51	
20	20	1.630	1.497	0.033	0.133	1.20	
21	21	1.040	1.136	0.083	-0.096	-1.18	
22	22	1.360	1.497	0.033	-0.137	-1.23	
23	23	1.740	1.561	0.083	0.179	2.20	R
24	24	1.370	1.332	0.114	0.038	1.74	
25	25	1.340	1.346	0.114	-0.006	-0.26	
26	26	1.340	1.332	0.083	0.008	0.10	
27	27	1.370	1.341	0.114	0.029	1.32	
28	28	1.220	1.240	0.114	-0.020	-0.92	
29	29	1.250	1.246	0.114	0.004	0.16	
30	30	1.240	1.280	0.114	-0.040	-1.83	
31	31	1.220	1.202	0.114	0.018	0.82	
32	32	1.620	1.651	0.114	-0.031	-1.41	
R denotes an observation with a large standardized residual/unusual observations							

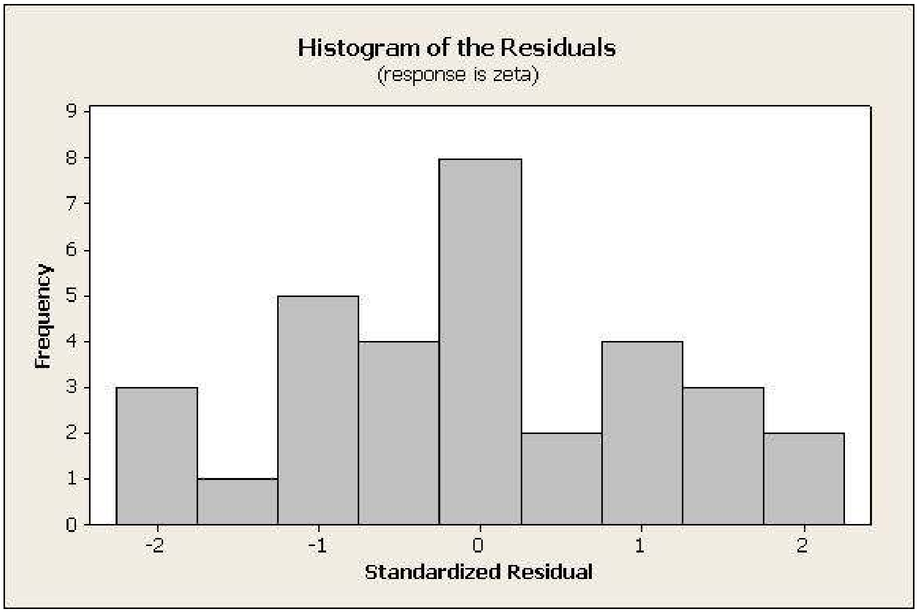


Fig 5.4 Histograms of the residuals for ξ

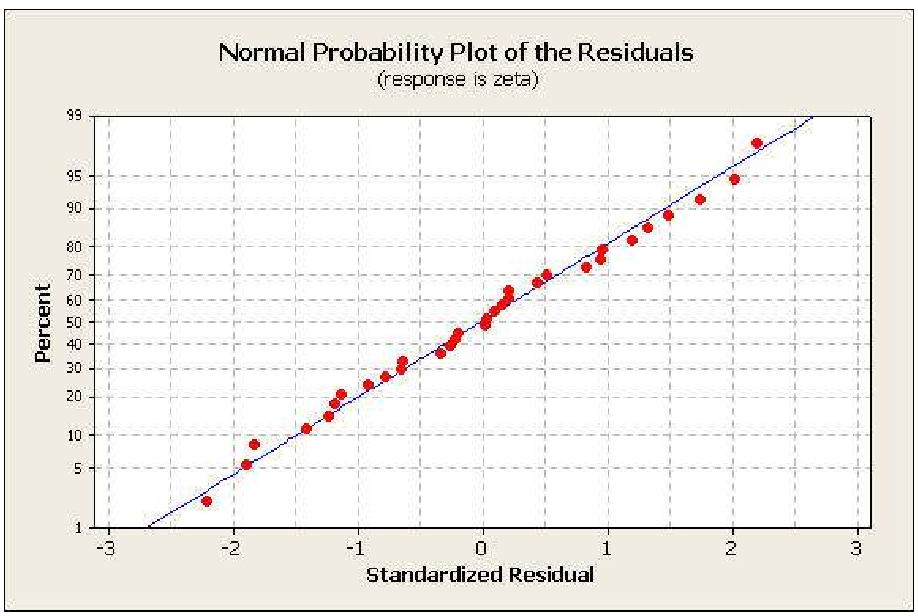


Fig 5.5 Normal probability plot of the residuals for ξ

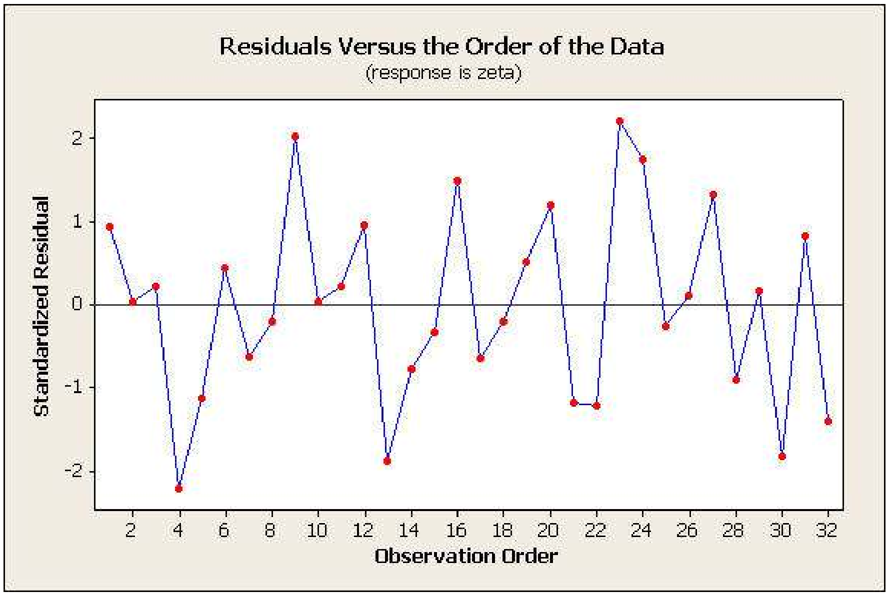


Fig 5.6 Residuals vs the order of the data for ξ

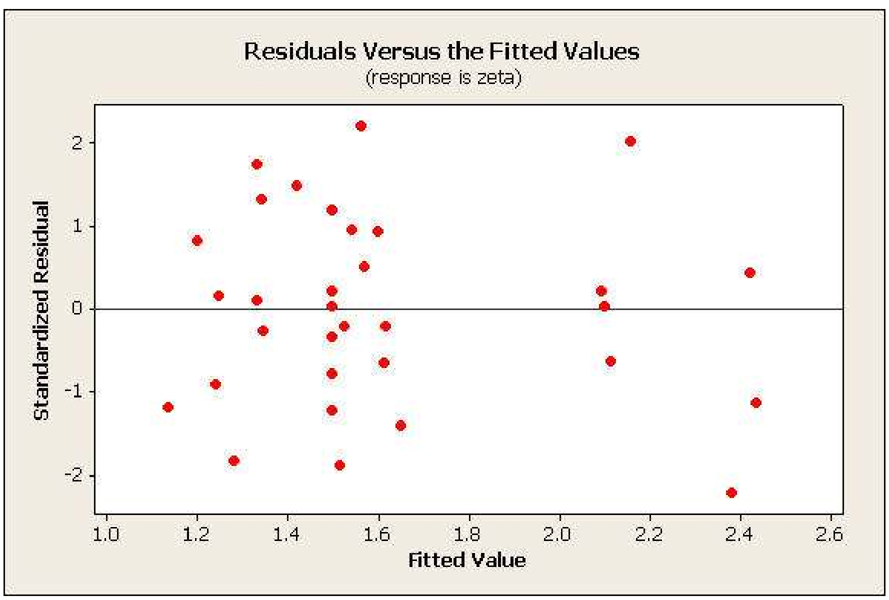


Fig. 5.7 Residuals vs the fitted values for ξ

5.2 RSM for chip length

From table 6, analyzing of variance shows that the terms have values of probability more than 0.05 which make them insignificant. Since all the linear, square and interaction terms are insignificant in this case, which is not possible. Hence, it concludes that error has crept into the model and it requires repetition.

Table 7 of estimated regression coefficients using coded units show that almost all the factors have a high probability value of being insignificant.

In table 8 of unusual observation of ξ, two values show a large standardized residual unusual observation implying that the observations are not correct and are to be repeated.

In fig. 5.8, the histogram of residuals is shown that has a normal distribution with a few observations deviating from the normal curve. If this assumption is valid, a histogram plot of the residuals should look like a sample form a normal distribution.

In fig. 5.9, the graph of normal probability plot vs residuals shows that most of the points are near the line implying the residual is normal. Observations showing standardized residual greater than 2 and less than -2 are to be investigated and may be the experiments repeated to get the adequate model.

In fig. 5.10, the graph of residuals vs fitted values, the values which are greater than 2 and less than -2 are insignificant

In fig. 5.11, we check the correlation between residuals by plotting residuals in sequence and the graph of residual vs order of data shows the standardized residual for the run order of experiment. This implies that the residuals are random in nature and don't exhibit any pattern with run order.

Table 6 Analysis of Variance for chip length L

Source		DF	Seq SS	Adj SS	Adj MS	F	P
Regression		20	8141	8141	407.1	0.43	0.949
	Linear	5	3274	3274	654.8	0.70	0.636
	Square	5	3000	3000	599.9	0.64	0.675
	Interaction	10	1868	1868	186.8	0.20	0.992
Residual	Error	11	10313	10313	937.6		
	Lack-of-Fit	6	7120	7120	1186.6	1.86	0.257
	Pure Error	5	3194	3194	638.8		
Total		31	18455				

Table 7 Estimated Regression Coefficients for chip length (The analysis was done using coded units.)

Term	Coefficient	SE Coefficient	T	P
Constant	42.9896	8.751	4.913	0.000
s	0.1276	7.217	0.018	0.986
f	9.4497	7.217	1.309	0.217
d	6.9274	7.217	0.960	0.358
H	-2.4914	7.217	-0.345	0.736
W	-6.1950	7.217	-0.858	0.409
s*s	-1.0742	19.520	-0.055	0.957
f*f	9.0128	19.520	0.462	0.653
d*d	-24.9582	19.520	-1.279	0.227
H*H	-2.9642	19.520	-0.152	0.882
W*W	26.0388	19.520	1.334	0.209
s*f	-0.2224	7.655	-0.029	0.977
s*d	0.0076	7.655	0.001	0.999
s*H	-2.4852	7.655	-0.325	0.752
s*W	-1.0111	7.655	-0.132	0.897
f*d	-5.1058	7.655	-0.667	0.519
f*H	-7.3683	7.655	-0.963	0.356
f*W	2.7861	7.655	0.364	0.723
d*H	-3.6881	7.655	-0.482	0.639
d*W	-2.7794	7.655	-0.363	0.723
H*W	-0.2182	7.655	-0.029	0.978
S = 30.62	R-Sq = 44.1%		R-Sq(adj) = 0.0%	

Table 8 Unusual observation for chip length

Obs	Std Order	L	Fit	SE Fit	Residual	Std Residual	remark
1	1	17.857	11.196	30.072	6.661	1.15	
2	2	33.203	28.819	30.072	4.384	0.76	
3	3	10.537	11.104	21.819	-0.567	-0.03	
4	4	16.625	26.553	30.072	-9.928	-1.72	
5	5	43.253	49.772	30.072	-6.519	-1.13	
6	6	57.925	63.804	30.072	-5.879	-1.02	
7	7	49.699	43.678	30.072	6.021	1.04	
8	8	49.009	53.252	30.072	-4.243	-0.74	
9	9	69.931	59.862	30.072	10.069	1.75	
10	10	37.385	42.990	8.751	-5.605	-0.19	
11	11	24.957	42.990	8.751	-18.033	-0.61	
12	12	29.518	42.553	21.819	-13.035	-0.61	
13	13	13.289	42.517	21.819	-29.228	-1.36	
14	14	41.569	42.990	8.751	-1.421	-0.05	
15	15	90.955	42.990	8.751	47.965	1.63	
16	16	79.168	42.043	21.819	37.125	1.73	
17	17	75.837	61.452	21.819	14.385	0.67	
18	18	48.553	75.223	21.819	-26.670	-1.24	
19	19	90.854	62.833	21.819	28.021	1.30	
20	20	20.508	42.990	8.751	-22.482	-0.77	
21	21	6.013	41.788	21.819	-35.775	-1.67	
22	22	37.162	42.990	8.751	-5.828	-0.20	

Obs	Std Order	L	Fit	SE Fit	Residual	Std Residual	remark
23	23	68.112	37.534	21.819	30.578	1.42	
24	24	69.429	66.506	30.072	2.923	0.51	
25	25	37.966	40.728	30.072	-2.762	-0.48	
26	26	26.876	24.959	21.819	1.917	0.09	
27	27	71.314	58.128	30.072	13.186	2.29	R
28	28	42.851	43.977	30.072	-1.126	-0.20	
29	29	57.019	54.736	30.072	2.283	0.40	
30	30	60.277	63.679	30.072	-3.402	-0.59	
31	31	83.889	83.243	30.072	0.646	0.11	
32	32	23.112	36.778	30.072	-13.666	-2.37	R
R denotes an observation with a large standardized residual.							

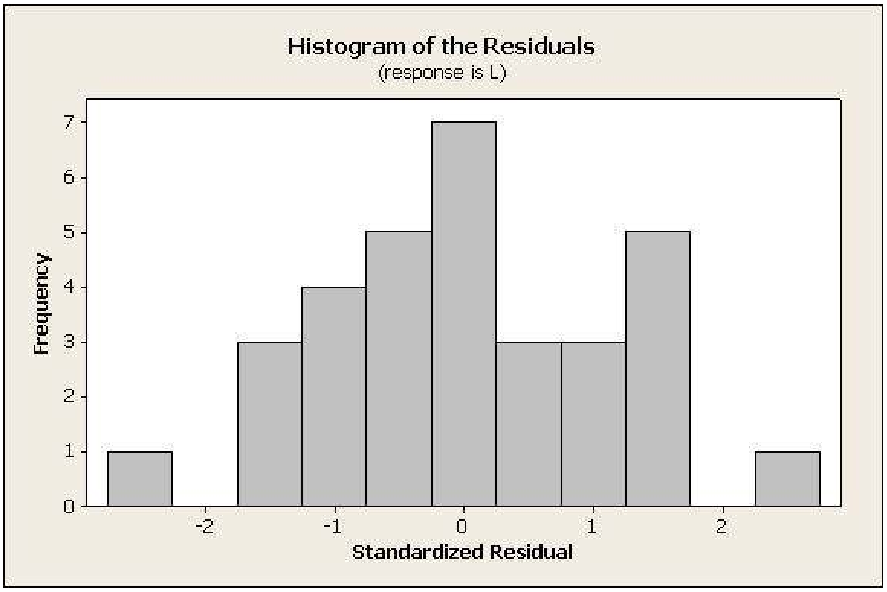


Fig 5.8 Histograms of the residuals for chip length

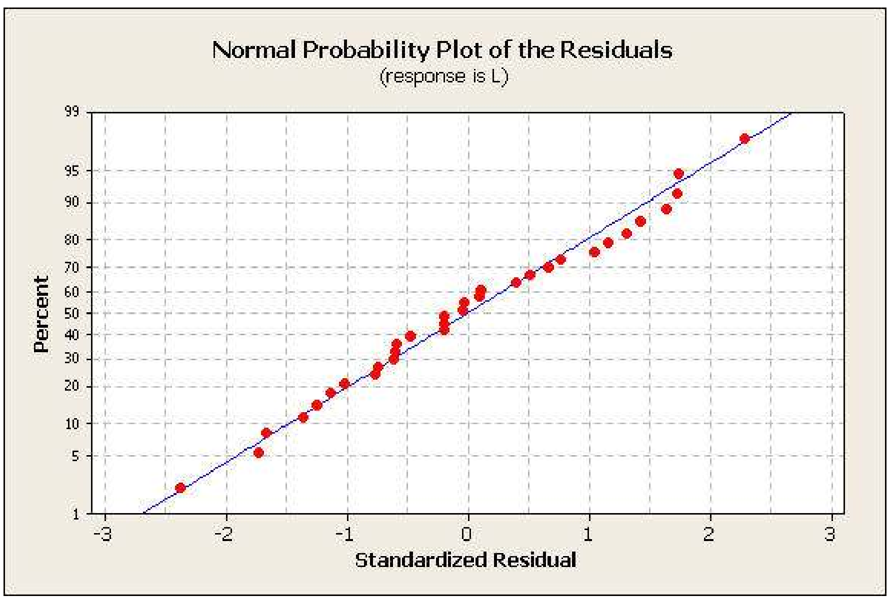


Fig 5.9 Normal probability plot of the residuals for chip length

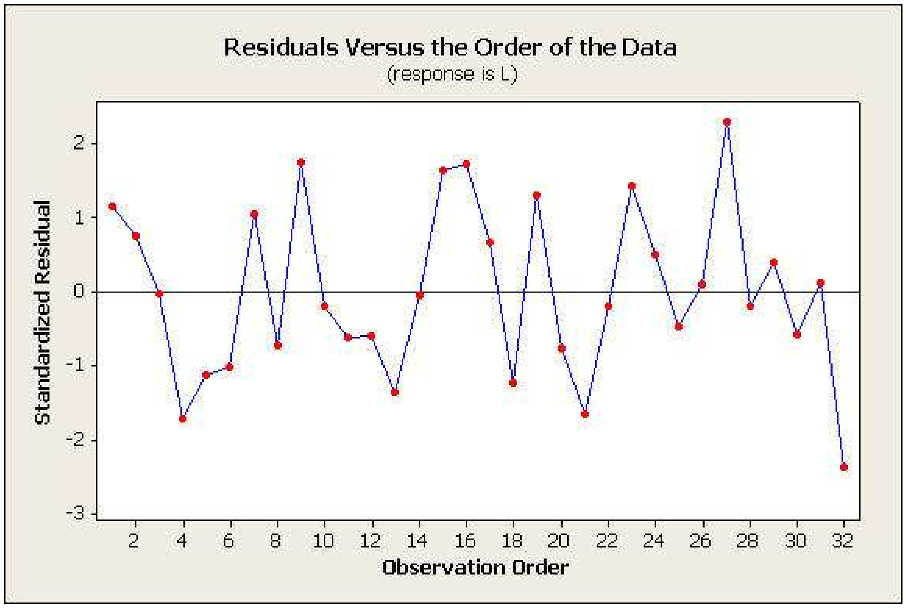


Fig 5.10 Residuals vs the order of the data for chip length

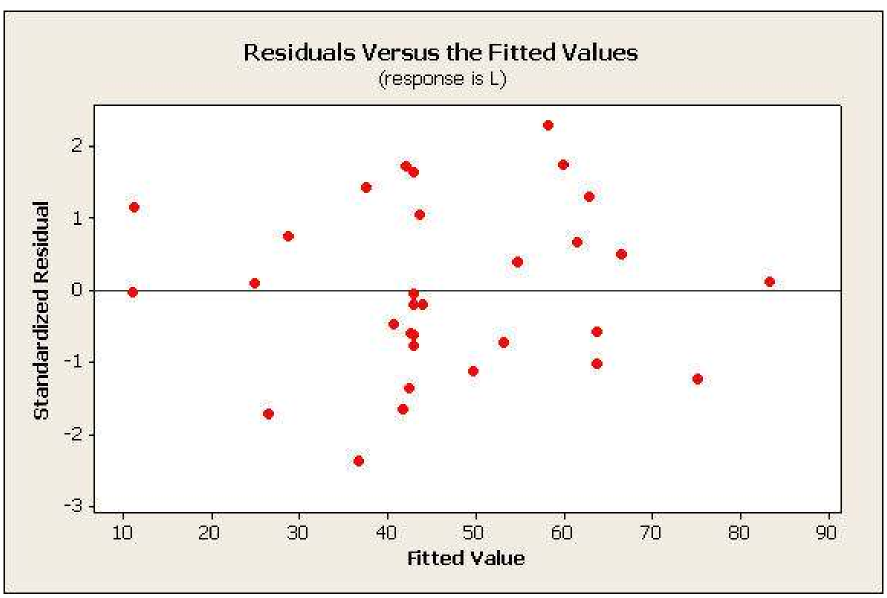


Fig. 5.11 Residuals vs the fitted values for chip length

Table 9 Estimated Regression Coefficients for ξ and chip length using data in uncoded units

Term	Coefficient for ξ	Coefficient for chip length
Constant	1.4852	254.318
s	0.1757	2.2692
f	-1.3517	10.715
d	-4.2948	558.025
H	-2.6773	301.182
W	-1.5065	-208.81
s*s	-0.0022	-0.0107
f*f	2.0179	225.319
d*d	5.3929	-623.96
H*H	1.8097	-131.74
W*W	0.0957	26.0388
s*f	0.02	-0.1112
s*d	-0.0506	0.0038
s*H	0.0408	-1.6568
s*W	0.0121	-0.1011
f*d	-0.1875	-127.65
f*H	-1.8333	-245.61
f*W	0.05	13.9303
d*H	0.0417	-122.94
d*W	0.4313	-13.897
H*W	-0.075	-1.4546

Developed equation for ξ:

ξ = 1.4852 + 0.1757*s -1.3517*f -4.2948*d -2.6773*H -1.5065*W -0.0022*s*s +2.0179*f*f + 5.3929*d*d +1.8097*H*H + 0.0957*W*W + 0.02*s*f -0.0506*s*d + 0.0408*s*H + 0.0121*s*W - 0.1875*f*d -1.8333*f*H + 0.05*f*W + 0.0417*d*H + 0.4313*d*W -0.075*H*W

Developed equation for chip length:

Chip length= 254.318 +2.2692*s +10.715*f +558.025*d +301.182*H -208.81*W -0.0107*s*s +225.319*f*f -623.96*d*d -131.74*H*H +26.0388*W*W -0.1112*s*f +0.0038*s*d -1.6568*s*H - 0.1011*s*W -127.65*f*d -245.61*f*H +13.9303*f*W -122.94*d*H -13.897*d*W -1.4546*H*W

CONCLUSION:

The effect of cutting speed, feed, depth of cut and chip breaker height and width on the chip breakability was studied.

It was found that chips of greater thickness are produced at low feed and depth of cut and it gradually decreases as feed and depth of cut increases.

Cutting speed and depth of cut are the most significant factors affecting the chip breakability and even their higher order terms play a significant role. The graphs obtained from histogram of residuals show a normal distribution. The graph of normal probability plot vs residuals shows that most of the points are near the line implying the residual is normal.

Thus, it was concluded that speed and depth of cut are most important factors in better control of chip.

REFERENCES:

[1] Kim J.D., Kweun O.B., A chip-breaking system for mild steel in turning, International Journal of machine tools manufacture, vol.37, no.5, (1997), 607-617.

[2] Mesquita R.M.D, Soares F.A.M., Barata Marques M.J.M., An experimental study of the effect of cutting speed on chip breaking, Journal of Materials Processing Technology, 56 (1996) 313-320.

[3] Hong-Gyoo Kim, Jae-Hyung Sim, Hyeog-Jun Kweon, Performance evaluation of chip breaker utilizing neural network, Journal of materials processing technology 2 0 9 (2 0 0 9) 647–656

[4] Das N.S., Chawla B.S., Biswas C.K., An analysis of strain in chip breaking using slip-line field theory with adhesion friction at chip/tool interface, Journal of Materials Processing Technology 170 (2005), 509–515

[5] Maity K.P., Das N.S., A slip-line solution to metal machining using a cutting tool with a step-type chip-breaker, Journal of Materials Processing Technology, 79, (1998), 217-223

[6] Rahman M., Seah K.W.H., Li X.P. and Zhang X.D.,A three-dimensional model of chip flow, chip curl and chip breaking under the concept of equivalent parameters, Int. J. Mach. Tools Manufacture., Vol. 35, (1995) pp. 1015-1031.

[7] Sutter G., Chip geometries during high-speed machining for orthogonal cutting conditions, International Journal of Machine Tools & Manufacture 45 (2005) 719–726

[8] Komanduri R., Schroeder T., Hazra J., Turkovich B.F. von, Flom D.G., On the catastrophic shear instability in high-speed machining of an AISI 4340 steel, Journal of Engineering for Industry,104, (1982) 121–131

[9] Friedman M.Y., Lenz E., Investigation of tool-chip contact length in metal cutting, International Journal of Machine Tool Design and Research ,10 (1970) 401–416.

[10] Sutter G., Molinari G., Faure L., Klepaczko J.R., Dudzinski D., An experimental study of high speed orthogonal cutting, Transactions ASME, Journal of Manufacturing Science and Engineering ,12 (1998) 169–172.

[11] Dabade Uday A., Joshi Suhas S., Analysis of chip formation mechanism in machining of Al/SiCp metal matrix composites, Journal of Materials Process. Tech. (2009)

[12] B.L. Juneja, G.S. Sekhon, Fundamentals of metal cutting and machine tools, Wiley Eastern, New Delhi, India, 1987.

[13] T. Shi, S. Ramalingam, Slip-line solution for orthogonal cutting with a chip breaker and flank wear, International Journal Mechanical Science, 33 (9) (1991) 689–774.

[14] B. Worthington and M. H. Rahman, Predicting breaking with groove type breakers, International Journal Mach. Tool Design Research,. 19, 121-132 (1979).