OPTIMIZATION OF TURNING PARAMETERS OF AISI 4340 STEEL USING TEXTURED CARBIDE TOOLS

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

in

DESIGN ENGINEERING

by

MANJARI MALVIYA

(1200456002)

Under the Supervision of

Dr. Sunil Kumar

Assoc. Professor

Department of Mechanical Engineering

Babu Banarasi Das University, Lucknow

BBD UNIVERSITY

to the

School of Engineering

BABU BANARASI DAS UNIVERSITY, LUCKNOW

June, 2022

CERTIFICATE

It is certified that the work contained in this thesis entitled **"Optimization of turning parameters of AISI 4340 steel using textured carbide tools"**, by **Manjari Malviya** (1200456002), for the award of **Master of Technology** from Babu Banarasi Das University has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

Signature
Dr. Sunil Kumar
Associate Professor
Department of Mechanical Engineering
BBD University, Lucknow

Date:

OPTIMIZATION OF TURNING PARAMETERS OF AISI 4340 STEEL USING TEXTURED CARBIDE TOOLS

Manjari Malviya

ABSTRACT

In present work, influence of turning parameters on surface roughness of AISI 4340 steel using textured tools is studied. For this, three types of surface textures, textures parallel to cutting edge, textures perpendicular to cutting edge, and dot textures made on rake face of carbide tool are used. Surface texturing on cutting tools is emerging as a green and promising technology in manufacturing industries for improving surface quality. Demand for textured tools is rapidly increasing in market as it helps in reducing manufacturing costs, yields higher productivity, and also safeguard health of operators and environment.

All experiments are performed on a lathe machine. The turning parameters considered are cutting speed (V), feed rate (f), depth of cut (t), and texturing type (TT) while surface roughness is considered the response variable. Firstly, feasibility of all types of textured tools with a non-textured tool is experimentally tested and verified. Secondly, a range of turning parameters is selected. Taguchi L_9 orthogonal array is applied within selected range and then turning parameters are optimized for minimum surface roughness. Finally, ANOVA is used and percentage contribution of each parameter is determined.

Feasibility study on AISI 4340 steel shows that textured tools help in improving surface quality as compared to non-textured tools. Percentage improvement in surface roughness using vertical textured tool is 14.65%, using horizontal textured tool is 22.89%, and using dot textured tool is 37.05%. Optimum level obtained from Taguchi Methodology are as follows: cutting speed = 120m/min, feed rate = 0.16mm/rev, depth of cut = 0.25mm and dot textured cutting tool. Percentage contribution of each turning parameter is observed as: cutting speed = 43.26%, feed rate = 11.48%, depth of cut = 0.207% and texturing type = 45.05%. Confirmation experiment shows an improvement in surface roughness by 59.91% when compared with initial setting.

ACKNOWLEDGMENT

I would like to express my sincere gratitude and respect to my thesis supervisor Dr. Sunil Kumar for his valuable guidance and assistance throughout my research study. I am very grateful to him for spending his precious time and energy in teaching me methodology and giving me valuable suggestions to complete my thesis work. I am very fortunate to be his student at BBD University, Lucknow.

I would like to sincerely thank all the faculties of the Department of Mechanical Engineering of BBD University, Lucknow for their encouragement and support. I am obliged to my parents, my sister, and all other people for their constant support and assistance in the successful completion of my thesis work.

Manjari Malviya

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Description
V	Cutting speed(m/min)
f	Feed rate(mm/rev)
t	Depth of cut(mm)
TT	Texturing type
Ra	Average surface roughness
n	Total no. of experimental runs

Abbreviation

ANOVA	Analysis of Variance
EDM	Electric Discharge Machine
DOC	Depth of cut
DF	Degree of freedom
PC	Percentage contribution
MS	Mean square
SS	Sum of squares
OA	Orthogonal Array

Greek letters

η	S/N ratio

CHAPTER 1

INTRODUCTION

1.1 TURNING

Turning is a metal cutting process in which a single-point cutting tool is used to remove unwanted material from a rotating workpiece to desired dimension and obtain desired surface quality. Mechanism of turning process is shown in fig. 1.1. The process requires a lathe machine, workpiece, and cutting tool.

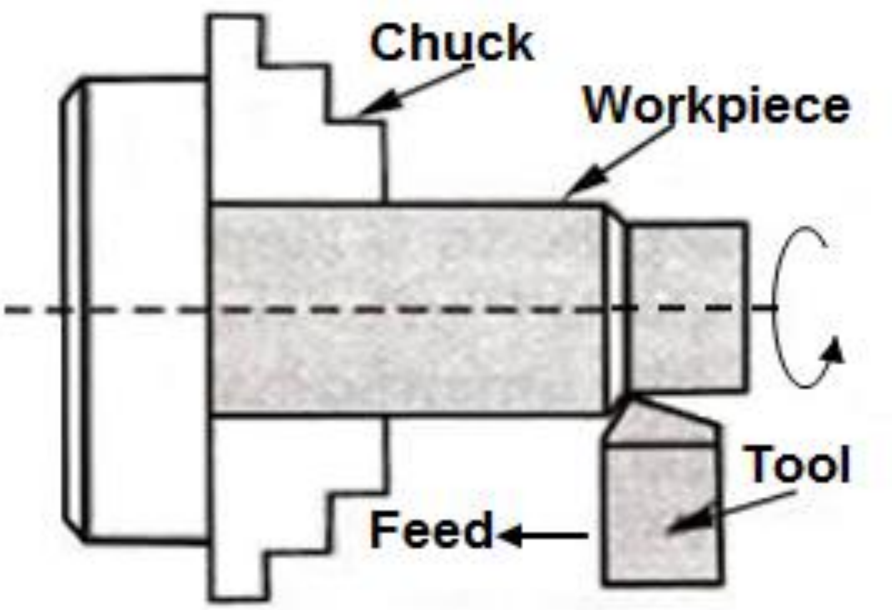

Fig. 1.1 Turning process [20]

Merits, demerits, and applications of turning are listed below:

1.1.1 Merits

- Almost all materials are compatible with process.
- Very good tolerances can be achieved.
- Requires no highly skilled operator.

- A better surface finish can be obtained.
- Material removal rate is good and flexible.

1.1.2 Demerits

- Machining time is too high.
- The process is limited to rotational parts.
- High tool wear.
- Requires high cutting forces.

1.1.3 Applications

- To produce rotational parts like cylindrical shafts and cone shafts.
- To produce asymmetric parts such as holes, grooves, and threads.
- To produce complex surfaces such as a keyhole, and spine shaft.

1.2 CUTTING TOOLS

Cutting tools are generally made of High-speed steel (HSS), ceramics, carbide, diamonds, and cubic boron nitride (CBN) to machine different materials such as steels, alloys, superalloys, composite materials, etc. Generally single-point cutting tools are required in turning process. Merits and demerits of single-point cutting tools over multi-point cutting tools are stated below.

1.2.1 Merits

- Design and fabrication are quite simple.
- Less time-consuming.
- Comparatively cheaper than multi-point cutting tool.

1.2.2 Demerits

- High tool wear.
- Shorter tool life.
- Low metal removal rate.

1.3 SURFACE TEXTURING

Manufacturing industries always compete with each other to produce products that are cheaper, more durable and possess good surface quality. Machining hard materials such as AISI 4340 steel is a major challenge faced by metal cutting industries because its high hardness that leads to low productivity and high manufacturing cost. Turning is a good approach to machine such hard materials but high friction and adhesion at tool-chip interface produce extreme temperatures at cutting zone which leads to high tool wear, reduction in tool life, and also deterioration of surface quality. Therefore, it is necessary to modify cutting tool in such a way that it produces a better-turned surface.

Surface texturing is relatively a new application that overcomes above-stated drawbacks by introducing different textures such as vertical, parallel, and dot at flank or rake face of cutting tool inserts. Surface texturing on rake face of cutting tool reduces cutting forces, increases load-carrying capacity, and improves wear resistance and surface quality. Rake face textured tools reduce tool chip contact area and thus decrease cutting forces, cutting temperature, and friction coefficient at tool-chip interface (Jianxin et al., 2012). Gap provided between grooves in textured tools help in heat dissipation from tool surface when chip slides over tool face, thus reducing cutting temperature at tip of cutting edge (Xie et al., 2013). Microscale parallel textures made on rake face of cutting tool reduce friction on surface of tool and cutting forces (Kawasegi et al., 2009).

Textured tools help in destabilizing built-up edge resulting in a better surface quality (Kummel et al., 2015). Surface roughness obtained by using rake face textured tools increases by increasing rake angle (Du et al., 2017). Micro textures produced on rake face of carbide tool reduce friction coefficient and also improve lubrication of tool (Sugihara et al., 2017). There are no certain guidelines made for designing the textures and thus, machining parameters can be optimized using trial-and-error methods only (Sharma and Pandey, 2016).

Researchers have found that texturing of cutting tools can improve machining performance of various materials by reducing machining zone temperature, decreasing machining forces, and improving wear resistance of cutting tools (Arslan et al., 2016). Good surface texturing provides important improvements in tribological characteristics, corrosion resistance, fatigue strength, and aesthetic appearance of product.

Textures made on rake face of cutting tool are of different types:

1. **Horizontal textures**- textures made perpendicular to cutting edge.
2. **Vertical textures**- textures made parallel to cutting edge.
3. **Dot textures-** microholes made on rake face of the tool at a short distance from the cutting edge.

1.3.1 CAPABILITIES OF SURFACE TEXTURING

1.3.1.1 Merits

Merits of surface texturing are discussed below:

- It can reduce friction and wear.
- Increases load carrying capacity and fluid film stiffness.
- It is also used to improve cutting performance of tools by enhancing lubricant availability at contact points, reducing tool-chip contact areas, and trapping wear debris.
- Reduces crater and flank wear, friction force, cutting forces, and cutting temperature.

1.3.1.2 Demerits

There are also certain limitations of surface texturing:

- Function of textures and optimal texturing parameters are very dependent on type of contact between tribo-pairs (parallel, wedged, line, or point contacts) and operating conditions.

- There is no universal selection of texture parameters that could generate beneficial effects for different working conditions.

- For certain contacts or working conditions (i.e., high-pressure, non-conformal contacts), benefit of surface texturing is negligible and may even become detrimental.

In this paper, surface texturing was performed on rake face of carbide cutting tool on an electronic discharge machine. EDM is a thermal material removal process that works on phenomenon of melting and vaporization. Mechanism of EDM is described in detail below.

1.4 MECHANISM OF EDM

When a charge is passed between electrode and workpiece, an electric field is developed in the gap and microscopic particles that are present in non-conducting fluid get accumulated at field's strongest point, thus building a high conductivity bridge across the gap. On increasing voltage, material in bridge heats up ionizing same particles to form a channel between electrode and workpiece. The increasing temperature and pressure finally generate a spark and a small amount of material melts and vaporizes from workpiece.

1.5 OPTIMIZATION METHODOLOGY

Many statistical-based techniques are used by researchers to optimize process parameters like Taguchi methodology (TM), Grey relation Analysis (GRA), and hybrid approaches like TM-GRA. These optimization techniques are discussed in detail.

1.5.1 Taguchi Methodology (TM)

Classical parametric design developed by R.A. Fisher (Fisher, 1976) stated that on increasing process parameters, number of experiments also increases which isn't practically feasible and also becomes a tedious job. Thus, to solve this problem, Taguchi introduced a robust design in which an orthogonal array is used which studies the entire parametric space with a small number of experiments. Taguchi L_9 OA estimates factors that influence performance criteria and then finds out which factors have a more significant effect on response variables than others.

Experimental results are then converted into a signal-to-noise (S/N) ratio. S/N ratio (η) is a ratio of mean to standard deviation which measures quality characteristics. Three methods are used in analysis of S/N ratio based on objective of experiment i.e., Lower-the-Better, Higher-the-Better, and Nominal-the-Better. A higher S/N ratio is preferred for analysis and it does not depend on type of quality characteristics. Therefore, optimal level of any machining parameter is decided based on higher average value of S/N ratio (Phadke, 1995; Mukherjee and Ray, 2006). Taguchi found out empirically that S/N ratio gives an optimal or near-optimal combination of factor levels.

Taguchi Methodology is useful for obtaining better combinations of machining parameters. Therefore, this technique is widely used for various metal cutting operations. TM excludes interaction between parameters and is best for a single-objective problem as well as for multi-objective problems. Taguchi technique gives a local optimum solution because it gives a single optimal solution therefore, it is also known as a one-time improvement technique as it helps in reducing cost of experiments. Researchers say that if this technique is combined with other optimization or modeling techniques, it will give better solutions as compared to the TM approach (Phadke, 1995; Yang and Tarng, 1998; Davim, 2003; Mukherjee and Ray, 2006).

1.5.2. Grey Relation Analysis (GRA)

GRA is the best technique to solve a complex multi-response problem in which impact and correlation between input factors are obscure. GRA is a multi-objective optimization technique that converts multiple responses into a single objective. In this technique, weights are assigned to each response variable.

The next step is to calculate a grey relation grade (GRG) which is further used to evaluate a multi-response problem. Researchers have found that this technique comes in handy when combined with Taguchi (Yang and Tarng, 1998; Deng, 1989).

In Taguchi Methodology, selection of weighting factor is posited on experience of a multi-objective optimization problem. For overcoming such problems, weighted grey relation analysis (GRA) is utilized to optimize multi-response parameters. The unreliability in selecting proper weights can be avoided by using entropy weight measurement method. Amongst all assigned weights, higher values of weight associated with quality characteristics are more effective (Sharma and Yadav, 2011; Adalarasan et al., 2015).

1.5.2 Hybrid Approach

Hybrid approach makes use of two or more optimization techniques to achieve objectives. A few examples of hybrid approaches are Taguchi combined with GRA (TM-GRA) and Taguchi combined with response surface methodology (TM-RSM). In TM-RSM approach, optimal parameters obtained from Taguchi optimization are used as a central value in RSM for modeling and optimization of parameters. This technique gives better results as compared to TM approach. On the other hand, in TM-GRA technique, GRA converts S/N ratio value of each quality characteristic into a single grey relation grade (GRG) (Shang 1995; Dubey and Yadava, 2008).

The main advantage of hybrid approach is that it eradicates limitations of each technique. It is useful in solving multi-response problems and compensates for limitations of TM approach. When machining parameters are computable and continuous, RSM is effective. When RSM is combined with Taguchi Methodology, RSM adjusts quantitative results obtained from TM and TM optimizes qualitative variables. Therefore, results derived from TM-RSM approach give a better result (Yadav, 2018).

TM-GRA is another hybrid technique in which GRA utilizes S/N ratios obtained from TM technique to optimize multi-objective problems. This technique is useful for solving multi-response problems.

This paper makes use of Taguchi optimization technique as here only a single objective is being studied. Taguchi method is best for single-objective problems as it provides orthogonal properties to experiments, reduces their costs, and also minimizes number of experiments.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Researchers over years have utilized different machining methods for improving surface quality of turned parts. Their sole aim was to find a better combination of turning parameters, cutting tools, materials of workpiece, and texturing methods to optimize turning parameters and get desired results.

A brief review of journals that had been studied is listed below in three parts viz. review related to turning parameters, review related to tool material, review related to surface texturing, and review related to Taguchi optimization technique.

2.2 REVIEW RELATED TO TURNING PARAMETERS

Prasath et al. (2018) studied effect of cutting speed, depth of cut, and feed rate on surface roughness during turning of EN 31 steel. They found that cutting speed was the most significant parameter which affected surface quality. Chandra et al. (2018) found that surface quality improved at a cutting speed of 350m/min and a feed rate of 0.15mm/rev. They also concluded that surface quality deteriorates at a higher feed rate. Moganapriya et al. (2018) analyzed effect of turning parameters during turning of AISI 1015 steel. Depth of cut was found as most influential parameter that affected surface quality. Patole and Kulkarni (2018) concluded that feed rate was a more significant factor in reducing surface roughness of AISI 4340 steel than DOC and cutting speed. Zerti et al. (2019) studied effect of varying turning parameters like cutting speed, feed rate, and depth of cut on surface roughness during turning of AISI 420 steel. They found that feed rate was the most significant factor that influenced surface roughness with a contribution of 80.71%.

Sahinoglu et al. (2020) investigated influence of turning parameters on surface quality of AISI 4140 steel and found that feed rate had maximum contribution to surface quality while cutting speed and depth of cut had negligible effects. They also concluded that surface roughness increases by increasing feed rate. Abbas et al. (2019) found optimum conditions for reducing surface roughness of AISI 1045 steel as: cutting speed = 116m/min, feed rate = 0.06mm/rev, and depth of cut = 0.25mm. They also inferred that surface roughness improves at a lower feed rate.

2.3 REVIEW RELATED TO TOOL MATERIAL

Choudhary and Paul (2019) studied turning effects on Ti alloy with coated and uncoated carbide inserts. They concluded that uncoated carbide tools were best choice for machining Ti alloys. They also concluded that for low tool wear, Ti alloys should be machined at a low cutting speed and feed rate. Koseki et al. (2016) developed a tin coating method for turning Ni-718 alloy. After experimentation, they found out that higher temperature stability and lower coating defects reduced damage to cutting tools and also increased tool life. Hoier et al. (2018) studied characteristics of carbide tools during turning of Ni-718 alloy. They concluded that a small variation in tool geometry caused by plastic deformation led to high tool wear. Qadri et al. (2020) studied effect of flank wear and surface roughness of Ni-718 alloy by varying cutting speed and hardness. They found out that as compared to silicon and mixed oxide cutting insert, Al-oxide cutting insert produced lower flank wear and better surface finish.

2.4 REVIEW RELATED TO SURFACE TEXTURING

Sawant et al. (2018) concluded that textured tools significantly help in reducing surface roughness. They performed a comparative analysis between spot and dimple textured tools at different cutting speeds and found out that spot-textured cutting tools produced better surface quality as compared to dimple-textured and non-textured tools. Rajbongshi and Sarma (2019) observed that texturing will produce lesser flank wear as compared to non-textured tools. They also found out that textured tool produced better surface quality and decreased cutting temperature. Pan et al. (2018) compared and analyzed surface roughness of steel using three different types of textured tools: vertical, parallel, and dot with a non-textured tool. They found that surface quality improved by increasing cutting speed in all types of textured tools. Koshy et al. (2011) performed turning on annealed 1045 steel and 6061 aluminum workpieces using an isotropic parallel textured tool with a width and depth of 100μm produced on rake face. They found a significant reduction in feed rate and improvement in surface quality.

Jesudass and Kalaichelvan (2018) performed a comparative analysis to study improvement in performance characteristics between a textured and a non-textured HSS tool on aluminum and steel. They found out that surface roughness of textured tools in case of aluminum was improved by 23.21 % and by 15.86% for mild steel. They also found a reduction in cutting forces and cutting temperature in case of texture tools. Kim et al. (2016) investigated effect of a micropatterned insert on characteristics of tool-workpiece interface during a turning process. They found that cutting forces in case of patterned insert were reduced by 2.7-10.9% as compared to non-patterned insert with decreasing feed rate and surface velocity. They also concluded that flank wear was improved by 9.7-11.4% when a patterned insert was used. Wei et al. (2017) found that texturing of tools helped in improving wear resistance as they reduced cutting zone temperature and machining forces. Siviah et al. (2020) found less BUE on tool edge in a cutting tool having surface texture grooves 45º inclined to main cutting edge when compared with other tools. Siviah et al. (2021) further continued their research and concluded that textured tools improved surface quality, tool wear, and cutting zone temperature as compared to non-textured tools.

Oliaei et al. (2016) studied influence of built-up edge formation on surface roughness in microscale orthogonal machining of titanium alloy Ti6Al4V and found that effect of BUE on surface quality varied depending on cutting speed and uncut chip thickness. They also obtained better values of surface roughness at a cutting speed of 62m/min.

2.5 REVIEW RELATED TO TAGUCHI OPTIMIZATION

Taguchi L_9 OA was also utilized by many researchers and it showed a significant improvement in all responses. Dureja et al. (2014) utilized Taguchi L_9 OA during turning of AISI D3 steel and found that feed rate was the most influential factor that affected surface quality. Kumar et al. (2020) used Taguchi methodology during turning of Titanium alloy (grade 5) and obtained a 5.8% improvement in surface quality and 21.26% improvement in S/N ratio. Rathod et al. (2022) utilized Taguchi L_9 OA in turning of SS 304 steel using carbide tools. Turning parameters considered were cutting speed, feed rate, and depth of cut. Based on results obtained, the best combination was found as: cutting speed = 350m/min, feed rate = 0.12mm/rev, and depth of cut = 0.40mm.

Hascalik and Caydas (2008) utilized Taguchi optimization technique during turning of Ti-6Al-4V and found out that at a cutting speed of 90m/min, feed rate of 0.15 mm/rev, and depth of cut 0.5 mm, improvement in surface roughness was found to be 244% as compared to initial setting. Mane and Kumar (2020) found minimum value of surface roughness of 52100 hardened alloy steel at an optimum condition of cutting speed = 140m/min, feed rate = 0.08mm/rev, and depth of cut = 0.19mm.

2.6 CONCLUSION FROM LITERATURE REVIEW

Following conclusion can be drawn from literature review:

1. Surface texturing is found to be a good technique for reducing surface hardness of workpieces through turning process.

2. Cutting speed, feed rate, and depth of cut were found to be the most significant turning parameters.

3. Carbide tools show their potential for cutting advanced engineering materials.

4. Taguchi Methodology is the most suitable technique for optimization of the turning parameters for a single-objective response as well as for multi-objective responses.

2.7 OBJECTIVE OF PRESENT WORK

Following objectives are drawn from literature review:

1. Development of vertical textured cutting tool.

2. Development of horizontal textured cutting tool.

3. Development of dot textured cutting tool.

4. Optimization of turning parameters of AISI 4340 steel using Taguchi L_9 OA technique.

2.8 ORGANIZATION OF THE THESIS

The present work is divided into four chapters. A brief description of chapters is listed below.

1. Chapter 1: Presents turning, cutting tools, surface texturing, mechanism of EDM, and optimization methodology.

2. Chapter 2: Presents a review of literature, conclusions from literature review, and objectives of present work.

3. Chapter 3: Presents surface texturing of cutting tools on EDM and feasibility study.

4. Chapter 4: Presents experimental studies on AISI 4340 steel using textured tools and optimization of turning parameters using TM approach.

5. Chapter 5: Presents main conclusions and recommendations for future work.

CHAPTER 3

TEXTURING OF TOOLS AND FEASIBILITY STUDY

3.1 GENERAL

In present chapter, procedure of surface texturing on carbide cutting tools for making three different textures- textures parallel to cutting edge, textures perpendicular to cutting edge, and dot textures are discussed. A copper electrode having a diameter of 500µm is used for making linear grooves and another copper electrode with a diameter of 1070µm is used for making microgrooves. Different types of textures which can be made at rake face of cutting tool are shown in fig. 3.1. Surface texturing conducted on EDM is shown in fig. 3.2. EDM is the best technique for making complex geometric shapes that have dimensions less than 100µm. It provides a greater choice for tool material; fewer machining forces are observed and mechanical stress is absent as there is no rotation involved.

Effect of turning parameters such as cutting speed (V), feed rate (f), depth of cut (t), and texturing type (TT) on surface roughness (Ra) is experimentally investigated for AISI 4340 steel. The following section describes surface texturing procedure conducted on EDM. The subsequent section describes details of experiment for three different textures made at rake face of cutting tool and feasibility study for textured tools and non-textured tools.

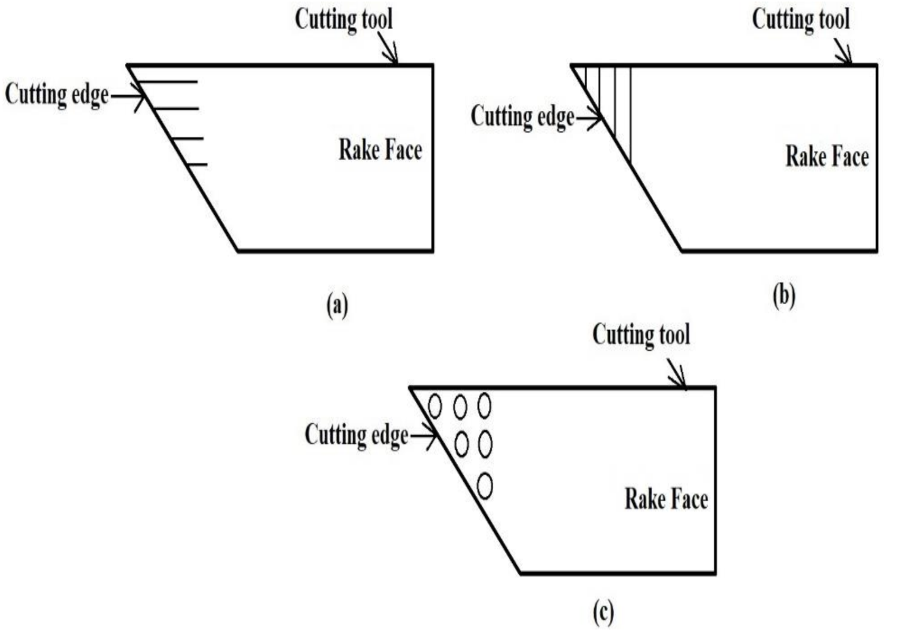

Fig. 3.1 Different types of texture patterns made at rake face of cutting tool (a) parallel to cutting edge; (b) perpendicular to cutting edge;(c) dot pattern

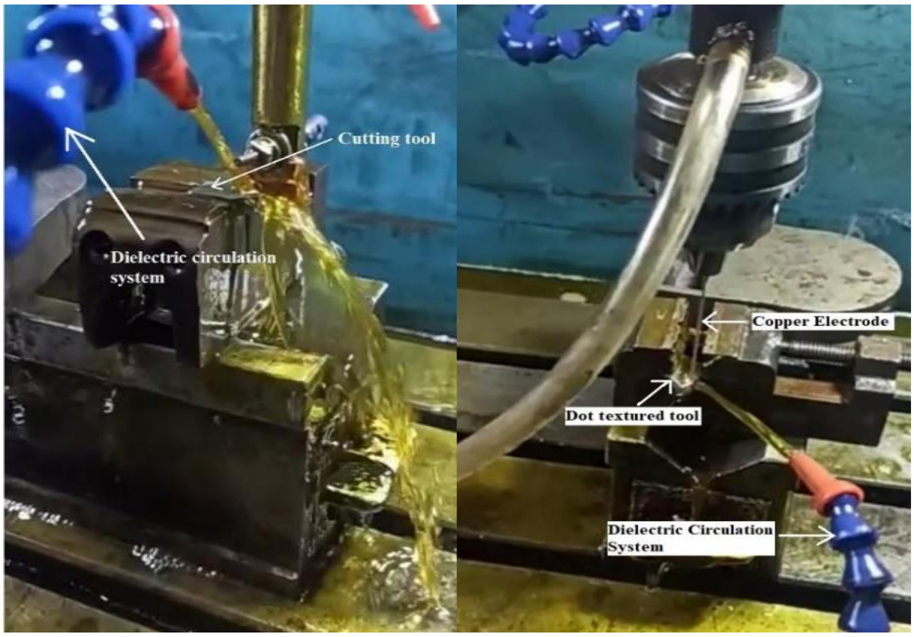

Fig. 3.2 Surface Texturing conducted on EDM

3.2 SURFACE TEXTURING ON EDM

Cutting tool inserts used for experimentation are carbide with ISO designation of E10-TH20. A ZNC 25 EDM machine with a capacity of 250 L is used for making textures on cutting tool as shown in fig. 3.3. A copper electrode with a diameter of 1070µm is used for making micro holes or dot patterns. 12 micro holes with a diameter of 1070µm are made on rake face of cutting tool at a distance of 50µm from cutting edge. Gap between two dots and spacing between two consecutive lines is kept at 100µm and depth of micro-holes is kept at 50µm. Final dot texture made on carbide tool along with its schematic explanation is shown in fig. 3.4.

Fig. 3.3 Electronic Discharge Machine

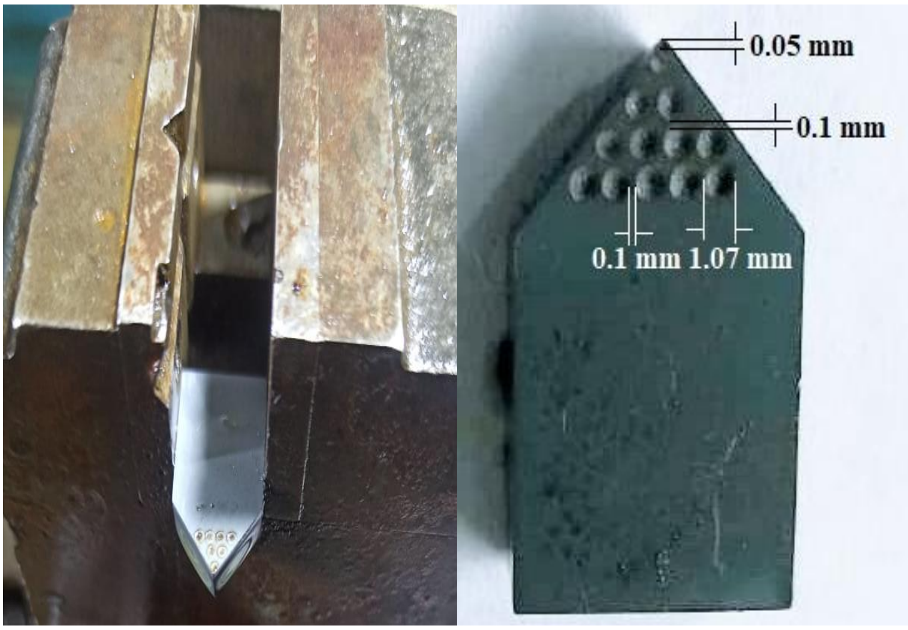

Fig. 3.4 Dot textured tool and its schematic explanation

For line textures, a copper electrode with a diameter of 500μm is used. Distance between two consecutive lines is kept at 100μm and depth of line textures is kept at 50μm. Texturing performed on carbide tools on EDM to obtain line textures is shown in fig. 3.5. Final line textures made by EDM are depicted in fig. 3.6 and schematic explanation of line textures are described in detail in fig. 3.7.

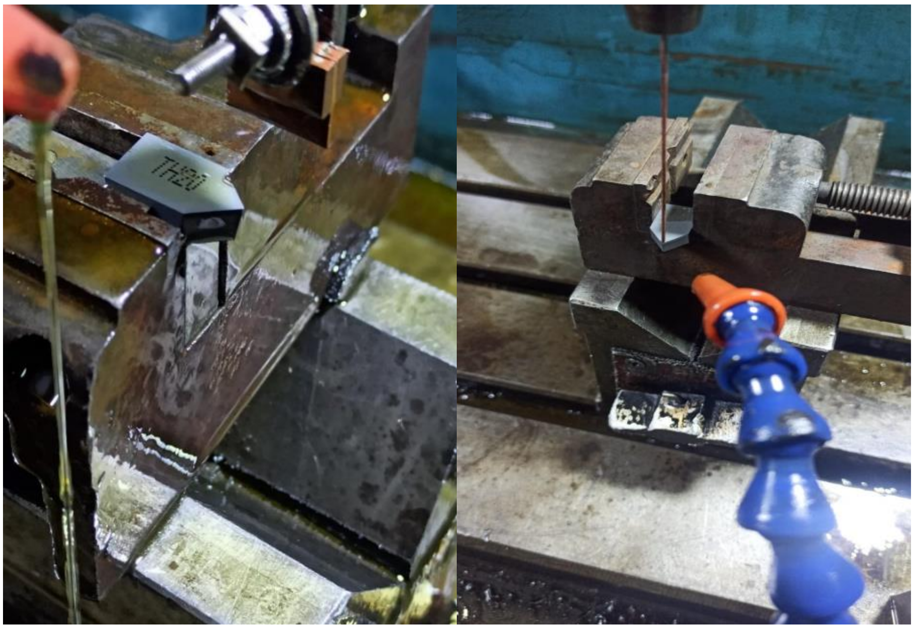

Fig.3.5 Texturing on carbide tools to obtain line textures

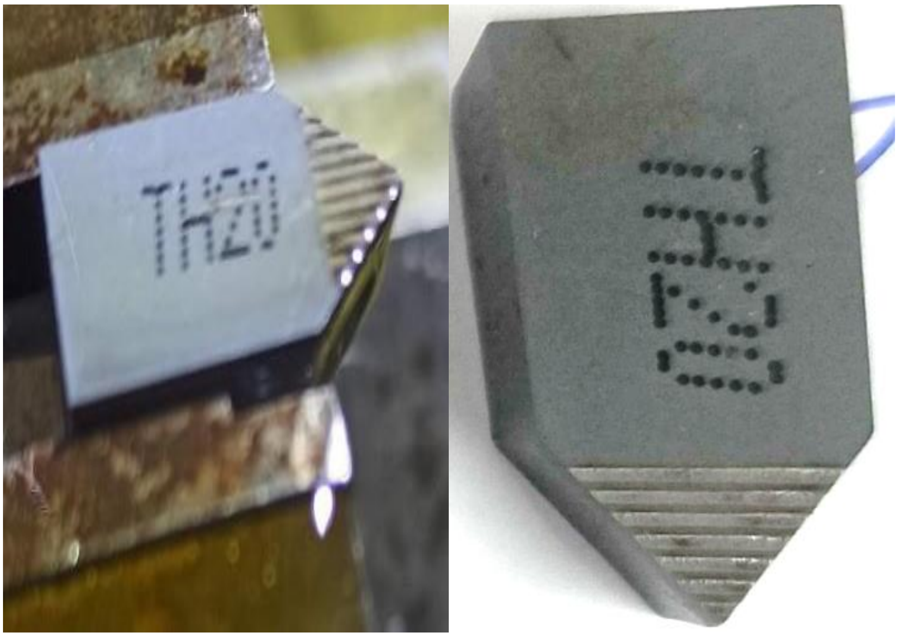

Fig.3.6 Final line textures made by EDM

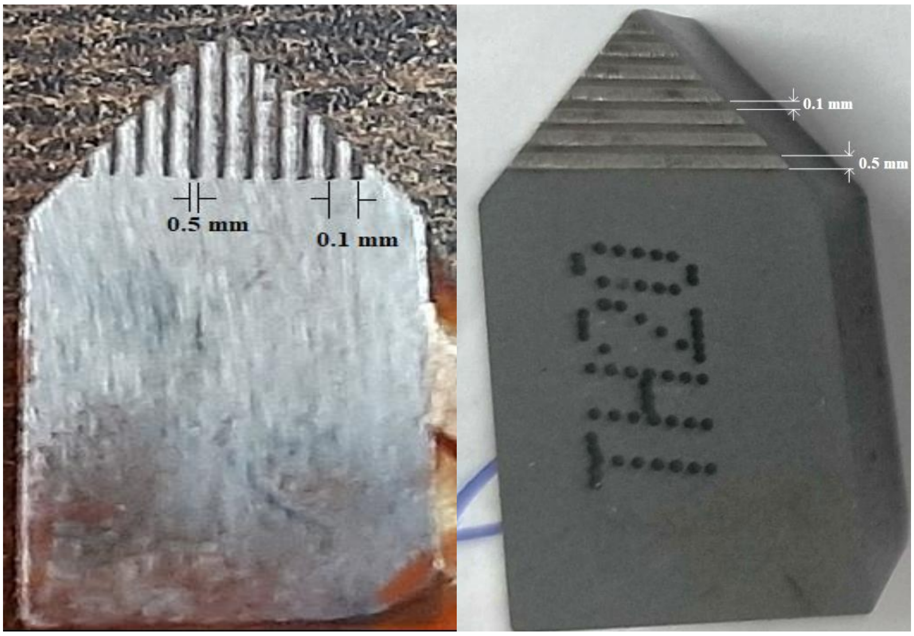

Fig.3.7 Schematic explanation of line textures.

Non-textured and textured inserts are then brazed on cutting tool holders as shown in fig. 3.8. Nomenclature of cutting tool holder is shown in Table 3.1. Specifications of lathe machine which is used in the experiment are given in Table 3.2. A digital surface measuring instrument, Surface Roughness Tester (TR-200) is used for measuring surface roughness values of turned parts. Its specifications are listed in Table 3.3. Values are measured at different points for a single turned surface and then their average values are used for analysis. Cut-off length used for measuring surface roughness is taken as 0.8mm.

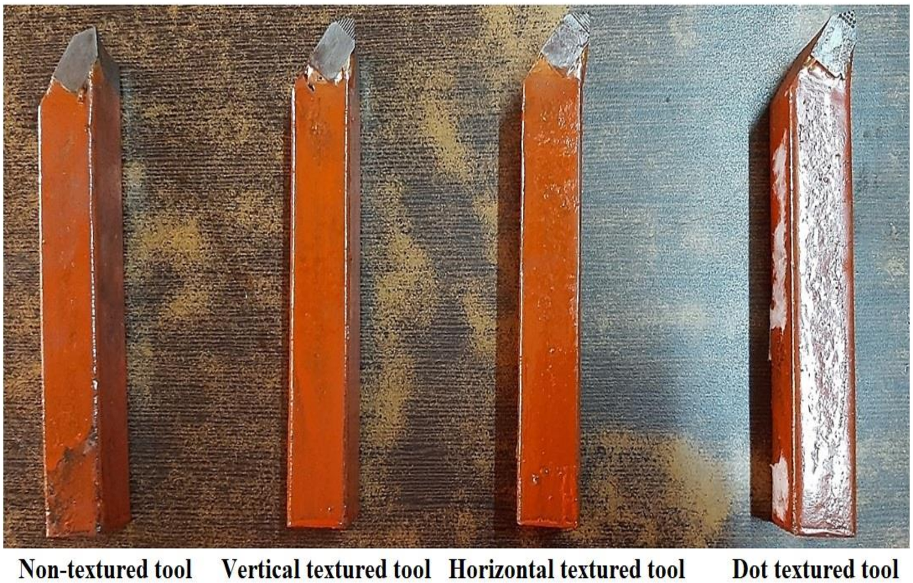

Fig. 3.8 Cutting tool holders

Turning is then performed on AISI 4340 steel using these textured tools. The setup in actual condition for line textured tools is shown in fig. 3.9. The setup in actual condition for dot and non-textured tools is shown in fig. 3.10.

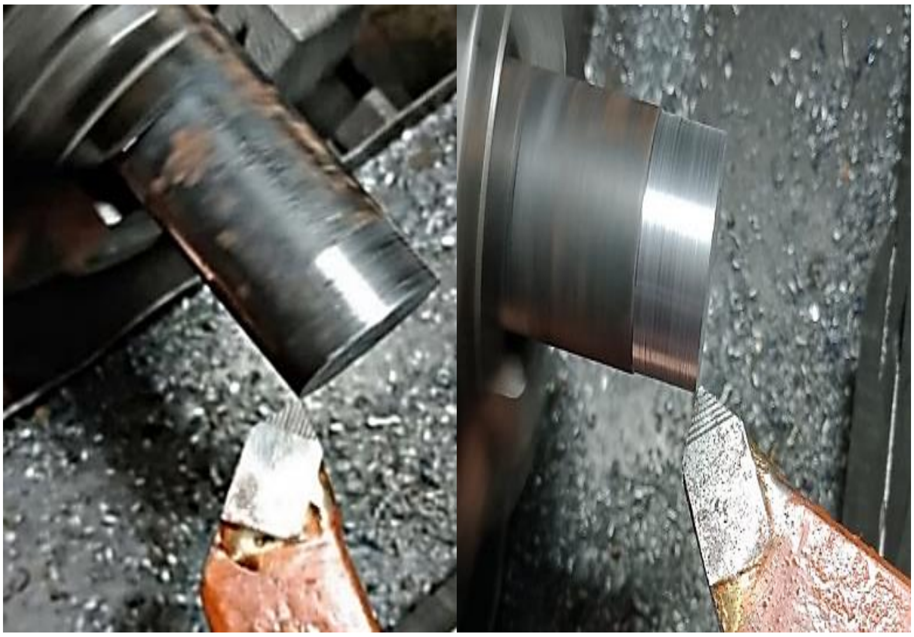

Fig. 3.9 Setup in actual condition for vertical and horizontal textured tools.

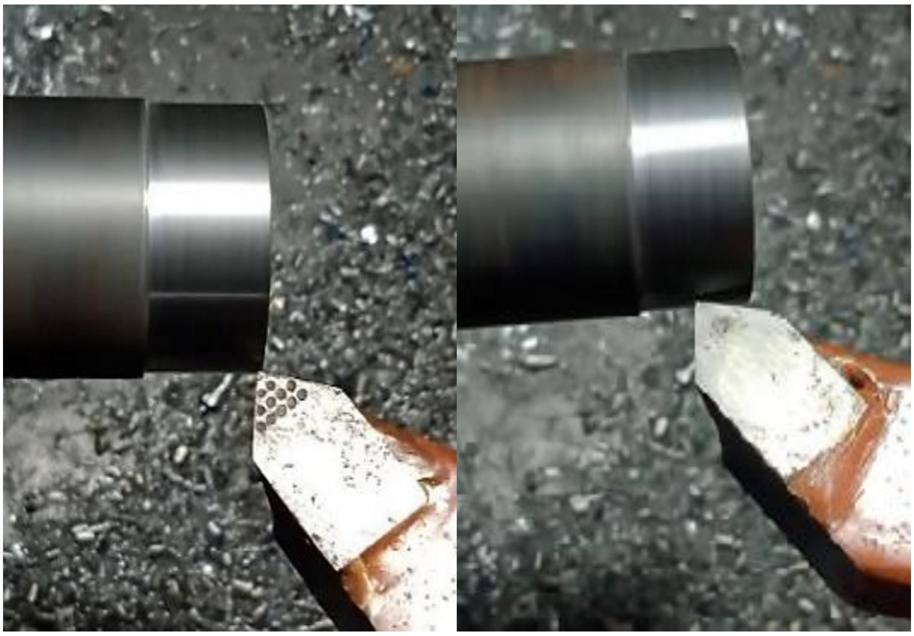

Fig. 3.10 Setup in actual condition for dot and non-textured tools.

Table 3.1 Nomenclature of cutting tool and cutting tool holder

Specifications	Units
Tool cutting edge angle	93º
Orthogonal rake angle	-6º
Shank width	20mm
Length	125mm
Hand	L

Table 3.2 Specifications of lathe machine

Element	Specifications
Manufacturer	BDS
Range of spindle speed	45-800 rpm
Height of centers	200 mm
Diameter of a hole through the spindle	41 mm
Required H.P.	1.5 KW (2HP)

Table 3.3 Specifications of surface roughness tester (TR 200)

Element	Description
Measuring system	Metric µm, Imperial µ inch
Display resolution	0.001 µm/ 0.04 µ inch
Display	LCD 128x64 dot matrix with black light
Dimension of screen	50 x 30 mm screen
Cut-of-length	0.8mm

3.3 FEASIBILITY STUDY

Superiority of textured tools over normal tools has been verified in feasibility study analysis by performing a comparative analysis. For experiment, constant values of turning parameters are used to analyze surface quality of AISI 4340 steel. The chemical and mechanical properties of AISI 4340 steel are shown in Tables 3.4-3.5.

Table 3.4 Chemical composition of AISI 4340 steel

Elements	% Weight
C	0.38-0.43
Mn	0.6-0.8
Si	0.15-0.35
Ni	1.65-2.00
Cr	0.7-0.9
Fe	Bal.

Table 3.5 Mechanical properties of AISI 4340 steel

Properties	Metric
Density (g/cm^3)	7.85
Melting temperature (ºC)	1427
Tensile Strength (MPa)	745
Fracture Toughness (MPa)	53-110
Poisson's Ratio	0.27-0.30

3.3.1 Feasibility study for Vertical textured tool

Feasibility of vertical textured tools has been verified by using different experimental conditions for vertical textured tools and non-textured tools for AISI 4340 steel. From Table 3.6 and fig. 3.11, surface roughness values for non-textured tools and vertical textured tools are found to be 3.201µm and 2.732µm respectively. Percentage improvement in response is seen as 14.65%.

It can be concluded that as compared to a non-textured tool, a vertical textured tool provides better surface roughness values for AISI 4340 steel.

Table 3.6 Turning conditions and response parameters for vertical and non-textured tools.

Turning parameter	Non-textured tool	Vertical textured tool
Cutting speed(m/min)	80	80
Feed rate(mm/rev)	0.16	0.16
Depth of cut(mm)	0.25	0.25
Surface roughness (µm)	3.201	2.732
Percentage Contribution		14.65%

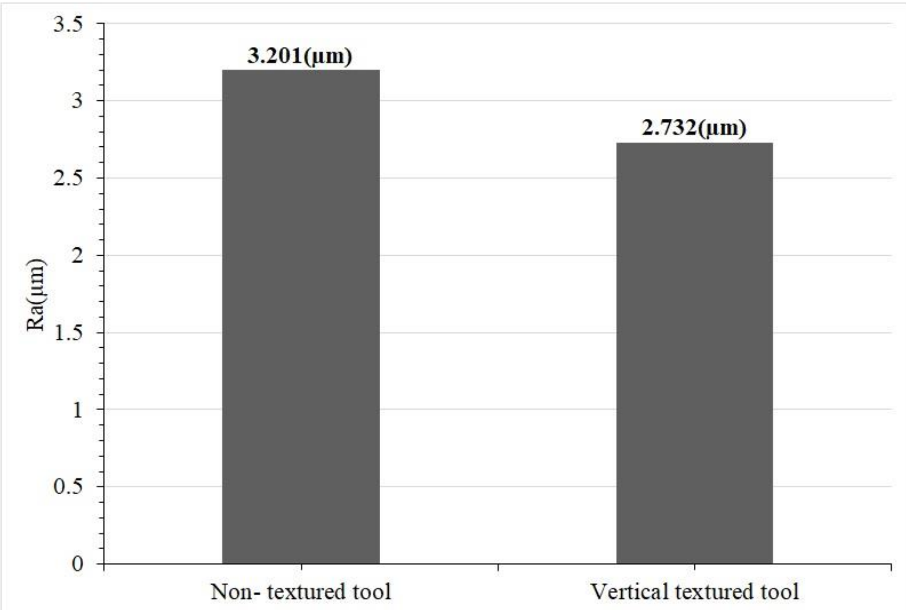

Fig. 3.11 Effect of turning parameters on Ra using vertical and non-textured tools

3.3.2 Feasibility study for Horizontal textured tool

Feasibility of horizontal textured tools has been verified by using different experimental conditions for horizontal textured tools and non-textured tools for AISI 4340 steel. From Table 3.7 and fig. 3.12, surface roughness values for non-textured tool and horizontal textured tool are found to be 3.201μm and 2.468μm respectively. Percentage improvement in the response is seen as 22.89%.

It can be concluded that as compared to non-textured tool, horizontal textured tool provides better surface roughness values for AISI 4340 steel.

Table 3.7 Turning conditions and response parameters for horizontal and non-textured tools.

Turning parameter	Non-textured tool	Horizontal textured tool
Cutting speed(m/min)	80	80
Feed rate(mm/rev)	0.16	0.16
Depth of cut(mm)	0.25	0.25
Surface roughness(μm)	3.201	2.468
Percentage Contribution		22.89%

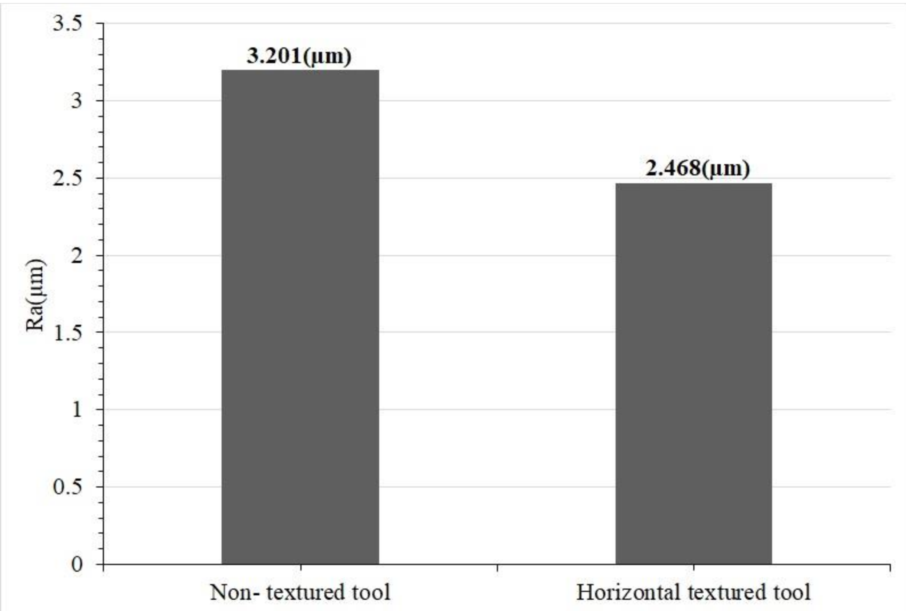

Fig. 3.12 Effect of turning parameters on Ra using horizontal and non-textured tools

3.3.3 Feasibility study for Dot textured tool

Feasibility of dot textured tools has been verified by using different experimental conditions for dot textured tools and non-textured tools for AISI 4340 steel. From Table 3.8 and fig. 3.13, surface roughness values for non-textured tools and dot textured tools are found to be 3.201µm and 2.015µm respectively. Percentage improvement in response is seen as 37.05%.

It can be concluded that as compared to non-textured tool, dot textured tool provides better surface roughness values for AISI 4340 steel.

Table 3.8 Turning conditions and response parameters for dot and non-textured tools.

Turning parameter	Non-textured tool	Dot textured tool
Cutting speed(m/min)	80	80
Feed rate(mm/rev)	0.16	0.16
Depth of cut(mm)	0.25	0.25
Surface roughness(µm)	3.201	2.015
Percentage Contribution		37.05%

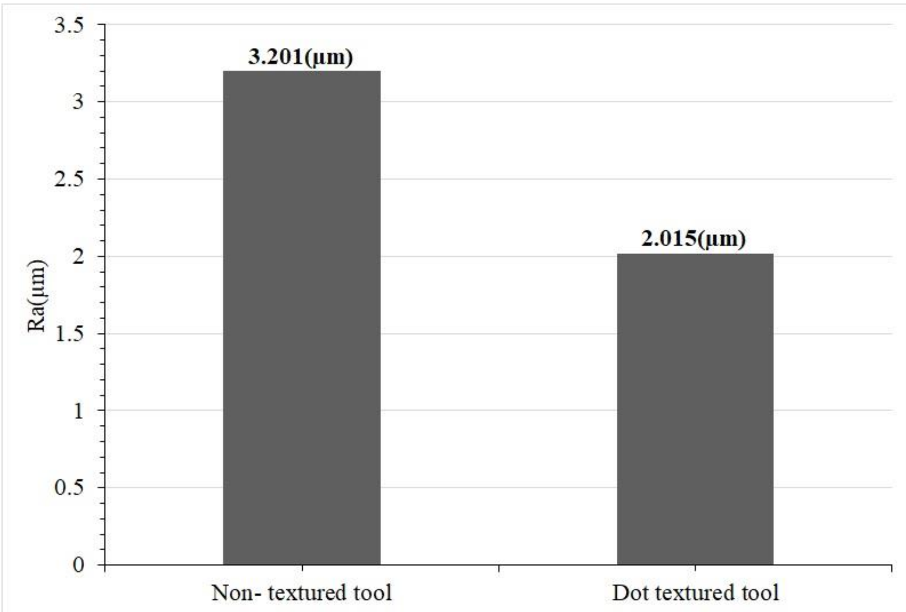

Fig. 3.13 Effect of turning parameters on Ra using dot and non-textured tools

3.4 Concluding Remarks

Feasibility of all three textured tools for AISI 4340 steel is experimentally verified. Range of machining parameters has been decided after conducting pilot experiments. After performing a careful analysis of the study, following conclusions can be drawn:

1. For same diameter of workpiece, textured tools provide a better surface finish as compared to a non-textured tool.

2. Average surface roughness obtained by using textured tools is comparatively lesser than by using a non-textured tool.

CHAPTER 4

EXPERIMENTATION

4.1 GENERAL

In present chapter, turning performed on AISI 4340 steel using textured carbide tools and optimization of turning parameters using Taguchi methodology (TM) has been discussed. Cutting speed (V), feed rate (f), depth of cut (t), and texturing type (TT) are taken as turning parameters and surface roughness is considered as a response parameter.

4.2 TURNING CONDITIONS

Range of turning parameters is decided after pilot experimentation. A minimum of three experiments at each level are performed to minimize variation. Values of factors and their levels are given in Table 3.9. Experiments are performed according to Taguchi L_9 OA. The OA depends on degree of freedom (DF) which can be calculated by equation (4.1) (Rose, 1996). For present case, four turning parameters and three levels (no interaction between factors) are selected. Degree of freedom can be calculated as:

$$\mathrm{DF} = [(\mathrm{level} - 1)\ \text{for each inputs} + (\mathrm{level} - 1) \times (\mathrm{level} - 1) + 1] \quad (4.1)$$

Therefore, a standard L_9 OA is selected for experiment, and experimental data according to L_9 OA is given in Table 3.10.

Table 3.9 Factors and their levels

Symbols	Factors	Level 1	Level 2	Level 3
V	Cutting speed (m/min)	80	100	120
f	Feed rate (mm/rev)	0.16	0.20	0.24
t	Depth of cut (mm)	0.25	0.50	0.75
TT	Texturing type	Vertical	Horizontal	Dot

Table 3.10 Experimental results using L_9 OA for textured cutting tools

Exp. No.	Input conditions				Response parameter	S/N ratio (η)
	V	f	t	TT	Ra	
1	1	1	1	1	2.732	-8.7296
2	1	2	2	2	2.468	-7.8469
3	1	3	3	3	2.015	-6.0855
4	2	1	2	3	1.622	-4.2010
5	2	2	3	1	3.997	-12.0346
6	2	3	1	2	2.512	-8.0003
7	3	1	3	2	1.171	-1.3711
8	3	2	1	3	1.213	-1.6772
9	3	3	2	1	2.214	-6.9035

4.2.1 Optimization using Taguchi Methodology

Taguchi optimization technique uses Signal to Noise (S/N) ratio (η) to measure quality characteristics of observed responses. Here, 'signal' denotes desirable value and 'noise' denotes undesirable value. TM optimizes turning parameters based on three criteria-smaller is better (SB), nominal is better, and higher is better (HB) respectively. In present case, minimum values of response (Ra) are desirable, therefore, S/N ratio for SB characteristic is used for computing optimum level. Mathematically, S/N ratio (η) for SB characteristic can be evaluated as follows (Rose, 1996):

$$\eta = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} y_i^2 \right] \qquad (4.2)$$

Here, y_i= observed response for i^{th}, n = number of trials.

S/N ratios for response parameters are calculated and are shown in Table 3.10. From Table 3.11 and fig. 3.14 it is observed that optimum levels for producing better surface quality are found to be: cutting speed = 120m/min at level-3, feed rate = 0.16mm/rev at level-1, depth of cut = 0.25mm at level-1 and dot texturing at level 3. Therefore, optimum level for response using TM technique is found to be V_3-f_1-t_1-TT_3.

Table 3.11 Average values of S/N ratio at each level

Mean S/N ratio	V	f	t	TT
Level 1	-7.5540	-4.7672*	-6.1357*	-9.2225
Level 2	-8.0786	-7.1862	-6.3171	-5.7394
Level 3	-3.3172*	-6.9964	-6.4970	-3.9879*

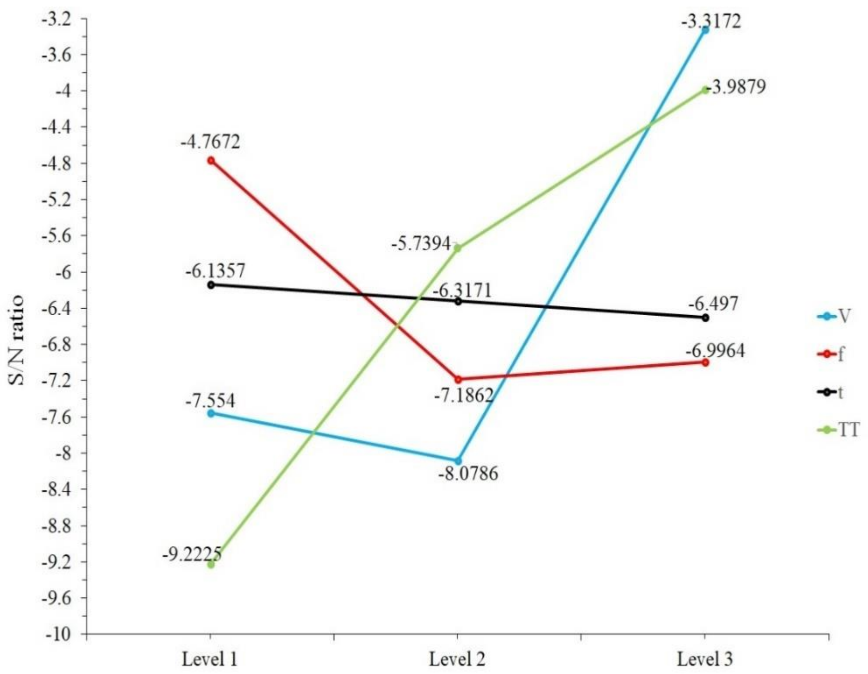

Fig 3.14 Effect of control factors on S/N ratio

1.2.2 ANOVA Analysis

In this section, S/N ratio values in Table 3.10 are used for calculating ANOVA. ANOVA is analyzed in form of adjusted sum of squares (SS), degree of freedom (DF), adjusted mean square (MS), F-ratio, and percentage contribution (PC). Results obtained after ANOVA analysis are shown in Table 3.12. Percentage contribution of four different control factors on response variable, Ra are as follows: cutting speed = 43.26%, feed rate = 11.48%, depth of cut = 0.207% and texturing type = 45.05% respectively. Percentage contribution of each turning parameter on surface quality has been shown graphically in fig. 3.15.

Table 3.12 ANOVA Analysis

Parameters	DF	Adj SS	Adj MS	F-ratio	PC (%)
V	2	40.90	20.448	208.77	43.26
f	2	10.86	5.428	55.44	11.48
t	2	0.1959	0.0979	1	0.207
TT	2	42.60	21.301	217.46	45.05
#Pooled error	--	0.1959#	0.0979	--	--
Total	8	94.55	--	--	--

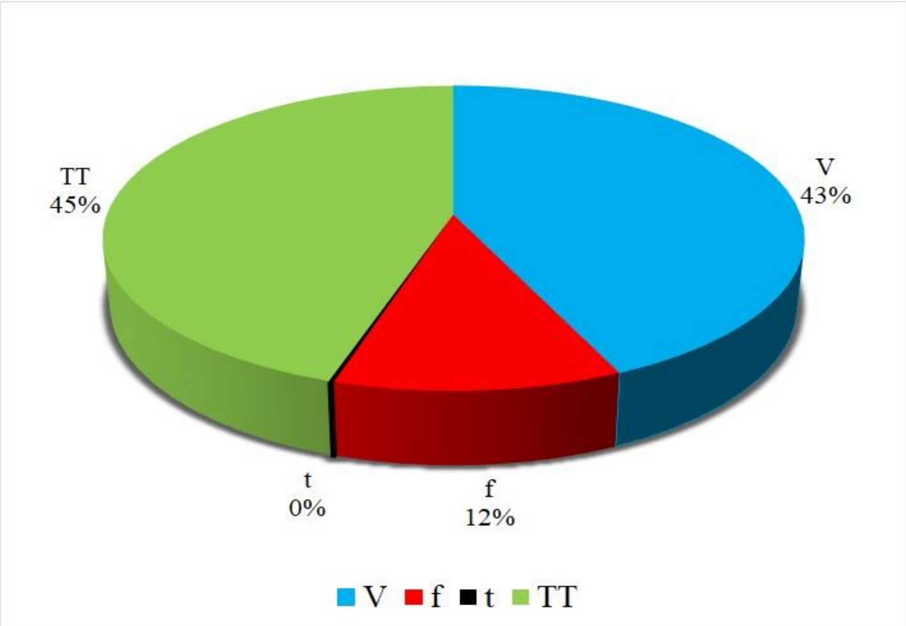

Fig. 3.15 Percentage contribution of each turning parameter on surface roughness

It is observed from Table 3.12 that texturing type has maximum contribution to surface quality followed by cutting speed, and feed rate while depth of cut has least effect.

4.2.3. Validation of optimal level

The confirmation experiment is performed to verify optimal conditions from TM analysis. From Table 3.11, V_3-f_1-t_1-TT_3 is found as the optimum level in which V_3 = 120m/min, f_1 = 0.16mm/rev, t_1 = 0.25mm and TT_3 = dot texturing. Experiments are performed at the above given conditions and then the surface roughness obtained is compared with the initial setting. It can be observed from Table 3.13 that percentage improvement in surface response is seen as 59.91%. Thus, experiments when performed at optimum level results in better surface quality.

Table 3.13 Confirmation Experiment

Initial setting		Optimum values	% Improvement
		Experiment	
Level	V_1-f_1-t_1-TT_1	V_3-f_1-t_1-TT_3	
Ra(µm)	2.732	1.095	59.91

CHAPTER 5

CONCLUSION AND SCOPE OF FUTURE WORK

5.1 CONCLUSION

In present work, application of surface texturing on cutting tools to improve surface quality has been shown and experimentally verified. Three different types of textures- textures parallel to cutting edge, textures perpendicular to cutting edge, and dot textures were made on rake face of a carbide cutting tool. Turning parameters were optimized through Taguchi L_9 technique. Based on experimental analysis, following conclusions can be drawn:

1. Surface texturing is a promising technique that can be used for improving surface quality.

2. Textured tools provide a better surface finish as compared to normal tools for AISI 4340 steel.

3. Percentage contribution of each turning parameter on surface quality are: cutting speed = 43.26%, feed rate = 11.48%, depth of cut = 0.207% and texturing type = 45.05%.

4. ANOVA analysis showed that texturing type had the most significant effect on surface quality followed by cutting speed while feed rate and depth of cut had least contribution.

5. Optimal level of turning parameter using Taguchi L_9 technique had been found as V = 120 m/min, f = 0.16 mm/rev, t = 0.25 mm, and TT = dot texturing for obtaining better surface roughness respectively.

6. Improvement in response obtained from confirmation experiment is 59.91% when compared with initial parameter value.

7. Among the three textures, dot textured cutting tool has been found as the most effective in reducing surface roughness and improving productivity.

1.2 SCOPE OF FUTURE WORK

1. Lubrication effect on surface quality has not been tested yet and will be implemented in future studies.

2. Effect of turning parameters like cutting speed, feed rate, depth of cut, and texturing type on other responses like cutting temperature, cutting forces, and tool wear has not been tested yet and will be implemented in future studies.

3. Effect of turning parameters on tool life, flank wear, and power consumption has not been tested yet and will be implemented in future studies.

4. In present work, only three textures that are vertical, horizontal, and dot were studied. Effect of other texturing patterns on surface quality can be studied in future.

5. Effect of textured tools on superalloys has not been tested yet and will be implemented in future studies.

REFERENCES

1. Abbas, A.T., Gupta, M.K., Soliman, M.S., Mia, M., Hegab, H., Luqman, M. and Pimenov, D.Y., 2019, *Sustainability assessment associated with surface roughness and power consumption characteristics in nanofluid MQL-assisted turning of AISI 1045 steel*, Int. J. Adv. Manuf. Technol, 105(1), pp.1311-1327.
2. Adalarasan, R., Santhanakumar, M. and Rajmohan, M., 2015, *Application of Grey Taguchi-based response surface methodology (GT-RSM) for optimizing the plasma arc cutting parameters of 304L stainless steel*, Int. J. Adv. Manuf. Technol., Vol. 78, Issue 5 (8), pp. 1161-1170.
3. Arslan, A., Masjuki, H.H., Kalam, M.A., Varman, M., Mufti, R.A., Mosarof, M.H., Khuong, L.S. and Quazi, M.M., 2016, *Surface texture manufacturing techniques and tribological effect of surface texturing on cutting tool performance: a review*, Crit. Rev. Solid State Mater. Sci., 41(6), pp.447-481.
4. Chandra, P., Rao, C.P. and Kiran, R., 2018, *Influence of machining parameter on cutting force and surface roughness while turning alloy steel*, Mater. Today: Proc., 5(5), pp.11794-11801.
5. Choudhary, A. and Paul, S., 2019, *Performance evaluation of PVD TIALN coated carbide tools vis-a-vis uncoated carbide tool in turning of titanium alloy (Ti-6Al-4V) by simultaneous minimization of cutting energy, a dimensional deviation and tool wear*, Mach. Sci. Technol., Vol. 23, Issue 3, pp. 368-384.
6. Davim, J.P., 2003, *Design of optimization of turning parameters for cutting metal matrix composites based on orthogonal arrays*, J. Mater. Process. Technol., Vol. 132, Issue 1 (3), pp. 340-344.
7. Deng, J., 1989, *Introduction to the grey system*, J. Grey Syst., Vol. 1, Issue 1, pp.1–24.
8. Du, S.Y., Chen, M.H., Zhu, Z.S. and Wang, X.N, 2017, *Experimental research on Surface Integrity of Milling New Ultra-High Strength Titanium Alloy TB17*, Modul. Mach. Tool Autom. Manuf. Tech., Vol. 4, pp. 125–129.
9. Dubey, A.K. and Yadava, V., 2008, *Multi-objective optimization of laser beam cutting process*, Opt. Laser Technol., Vol. 40, Issue 3, pp. 562-570.
10. Dureja, J.S., Singh, R. and Bhatti, M.S., 2014, *Optimizing flank wear and surface roughness during hard turning of AISI D3 steel by Taguchi and RSM methods*, Prod. Manuf. Res., 2(1), pp.767-783.
11. Fisher, R.A., 1976, *Statistical Methods for Research Workers*, London, Oliver and Boyd.
12. Hascalik, A. and Caydas, U., 2008, *Optimization of turning parameters for surface roughness and tool life based on the Taguchi method,* Int. J. Adv. Manuf. Technol., 38(9), pp.896-903.
13. Hoier, P., Malakizadi, A., Krajnik, P. and Klement, U., 2018, *Study of flank wear topography and surface-deformation of cemented carbide tools after turning Alloy 718*, Procedia CIRP, Vol. 77, pp. 537-540.
14. Jianxin, D., Ze, W., Yunsong, L., Ting, Q. and Jie, C., 2012, *Performance of carbide tools with textured rake-face filled with solid*

lubricants in dry cutting processes, Int. J. Refract. Met. Hard Mater., 30(1), pp.164-172.
15. Jesudass Thomas, S. and Kalaichelvan, K., 2018, *Comparative study of the effect of surface texturing on cutting tools in dry cutting*, Mater. Manuf. Processes, 33(6), pp.683-694.
16. Kawasegi, N., Sugimori, H., Morimoto, H., Morita, N. and Hori, I., 2009, *Development of cutting tools with microscale and nanoscale textures to improve frictional behavior*, Precis. Eng., 33(3), pp.248-254.
17. Kim, D.M., Lee, I., Kim, S.K., Kim, B.H. and Park, H.W., 2016, *Influence of a micropatterned insert on characteristics of the tool-workpiece interface in a hard turning process,* J. Mater. Process. Technol., 229, pp.160-171.
18. Koseki, S., Inoue, K., and Usuki, H., 2016, *Damage of physical vapor deposition coatings of cutting tools during alloy 718 turning*, Precis. Eng., Vol. 44, pp.41-54.
19. Koshy, P. and Tovey, J., 2011, *Performance of electrical discharge textured cutting tools*. CIRP Ann., 60(1), pp.153-156.
20. Kumar, S., Yadav, R.N. and Kumar, R., 2020, *Modeling and optimization of duplex turning of titanium alloy (grade 5) using Taguchi methodology-response surface methodology*, Int. J. Ind. Syst. Eng., 35(4), pp.463-481.
21. Kummel, J., Braun, D., Gibmeier, J., Schneider, J., Greiner, C., Schulze, V. and Wanner, A., 2015, *Study on micro texturing of uncoated cemented carbide cutting tools for wear improvement and built-up edge stabilization*, J. Mater. Process. Technol., 215, pp.62-70.
22. Mane, S. and Kumar, S., 2020, *Analysis of surface roughness during turning of AISI 52100 hardened alloy steel using minimal cutting fluid application*, Adv. Mater. Process. Technol., pp.1-12.
23. Moganapriya, C., Rajasekar, R., Ponappa, K., Venkatesh, R. and Jerome, S., 2018, *Influence of coating material and cutting parameters on surface roughness and material removal rate in turning process using Taguchi method*, Mater. Today: Proc., 5(2), pp.8532-8538.
24. Mukherjee, I., and Ray, P.K., 2006, *A review of optimization techniques in metal cutting processes*, Comput. Ind. Eng., Vol. 50, Issue 1 (2), pp. 15-34.
25. Oliaei, S.N.B., and Karpat, Y., 2016, *Investigating the influence of built-up edge on forces and surface roughness in micro-scale orthogonal machining of titanium alloy Ti6Al4V,* J. Mater. Process. Technol., 235, pp.28-40.
26. Pan, C., Li, Q., Hu, K., Jiao, Y. and Song, Y., 2018, *Study on surface roughness of Gcr15 machined by micro-texture PCBN tools*, Mach., 6(3), p.42.
27. Patole, P.B., and Kulkarni, V.V., 2018, *Optimization of process parameters based on surface roughness and cutting force in MQL turning of AISI 4340 using nanofluid*, Mater. Today: Proc., 5(1), pp.104-112.
28. Phadke, M.S., 1995, *Quality engineering using robust design*, New Jersey, Prentice Hall.
29. Prasath, K.M., Pradheep, T. and Suresh, S., 2018, *Application of Taguchi and response surface methodology (RSM) in steel turning process to improve surface roughness and material removal rate*, Mater. Today: Proc., 5(11), pp.24622-24631.

30. Qadri, S.I.A., Harmain, G.A. and Wani, M.F., 2020, *The effect of cutting speed and workpiece hardness on turning performance of nickel-based super Alloy-718 using ceramic cutting inserts.*, Eng. Res. Express, 2(2), p.025018.
31. Rajbongshi, S.K., and Sarma, D.K., 2019, *Performance parameters studies in the machining of AISI D2 steel with dot-textured, groove-textured & non-textured cutting tools at the flank face*, Int. J. Refract. Met. Hard Mater., 83, p.104970.
32. Rathod, N.J., Chopra, M.K., Chaurasiya, P.K., Vidhate, U.S. and Dasore, A., 2022, *Optimization on the Turning Process Parameters of SS 304 Using Taguchi and TOPSIS,* Ann. Data Sci., pp.1-15.
33. Rose, P.J., 1996, *Taguchi Technique for Quality Engineering*, New York, Tata McGraw-Hill.
34. Sahinoglu, A. and Rafighi, M., 2020, *Investigation of vibration, sound intensity, machine current, and surface roughness values of AISI 4140 during machining on the lathe,* Arab J. Sci. Eng., 45(2), pp.765-778.
35. Sawant, M.S., Jain, N.K. and Palani, I.A., 2018, *Influence of dimple and spot-texturing of HSS cutting tool on machining of Ti-6Al-4V*, J. Mater. Process. Technol., 261, pp.1-11.
36. Shang, J.S., 1995, *Robust design and optimization of material handling in an FMS*, Int. J. Prod. Res., Vol. 33, Issue 9, pp.2437-2454.
37. Sharma, A. and Yadava, V., 2011, *Optimization of cut quality characteristics during Nd: YAG laser-straight cutting of Ni-based superalloy thin sheet using grey relational analysis with entropy measurement*, Mater. Manuf. Process., Vol. 26, Issue 12, pp.1522-1529.
38. Sharma, V. and Pandey, P.M., 2016, *Recent advances in turning with textured cutting tools: a review.*, J. Cleaner Prod., 137, pp.701-715.
39. Sivaiah, P. and Bodicherla, U., 2020, *Effect of surface texture tools and minimum quantity lubrication (MQL) on tool wear and surface roughness in CNC turning of AISI 52100 steel*, J. Inst. Eng. (India): C, 101(1), pp.85-95.
40. Sivaiah, P., Revantha Kumar, M., Bala Subramanyam, S. and Prasad, K.L.V., 2021, *A comparative study on different textured and untextured tools' performance in the turning process*, Mater. Manuf. Process., 36(8), pp.926-935.
41. Sugihara, T. and Enomoto, T., 2017, *Performance of cutting tools with dimple textured surfaces: a comparative study of different texture patterns*, Precis. Eng., 49, pp.52-60.
42. Wei, Y., Kim, M.R., Lee, D.W., Park, C. and Park, S.S., 2017, *Effects of micro-textured sapphire tool regarding cutting forces in turning operations*, Int. J. Precis. Eng. Manuf. - Green Technol., 4(2), pp.141-147.
43. Xie, J., Luo, M.J., Wu, K.K., Yang, L.F. and Li, D.H., 2013, *Experimental study on cutting temperature and cutting force in dry turning of titanium alloy using a non-coated micro-grooved tool*, Int. J. Mach. Tools Manuf., 73, pp.25-36.
44. Yadav R.N., 2018, *An experimental study and parameters optimization on duplex turning of titanium alloy,* Mater. Perform. Charact., Vol. 7, Issue 1, pp. 423-444.
45. Yang, Y.H. and Tarng, Y.S., 1998, *Design optimization of cutting parameters for turning operations based on the Taguchi method*, J. Mater. Process. Technol., Vol. 84, Issue 1 (3), pp. 122-129.

46. Zerti, A., Yallese, M.A., Meddour, I., Belhadi, S., Haddad, A. and Mabrouki, T., 2019, *Modeling and multi-objective optimization for minimizing surface roughness, cutting force, power, and maximizing productivity for tempered stainless steel AISI 420 in turning operations*, Int. J. Adv. Manuf. Technol., Vol. 102, Issue 1 (4), pp. 135-157.

LIST OF PAPERS SUBMITTED

International Conferences:

1. Malviya M., Kumar S. and Anand A., Optimization of turning parameters of AISI 4340 steel using Dot Textured tool. *Proceedings of the International Conference on Processing and Characterization of Materials*. Sri Sivasubramaniya Nadar College of Engineering, Chennai, March 7-8, 2022.

2. Malviya M., Kumar S. and Anand A., Optimization of turning parameters of AISI 4340 steel using Parallel Textured Tool. *International Conference on Advancements in Interdisciplinary Research (AIR 2022), Theme: Smart and Sustainable Society.* Motilal Nehru National Institute of Technology Allahabad, and Nexance- The Next Generation Alliance for Scientific and Professional Advancements, May 6-7, 2022.