Experimental Investigation of Productivity Improvement of Machining Process Using Multi-Tool Turning

By

Kuba Defaru Nedi

A Thesis Submitted to Department of Mechanical Design and Manufacturing Engineering

School of Mechanical, Chemical and Materials Engineering

Office of Graduate Studies

Adama Science and Technology University

June, 2020

Adama, Ethiopia

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Approval Sheet

We, the undersigned, members of the Board of Examiners of the final open defense by **Kuba Defaru Nedi** have read and evaluated his thesis entitled **“Experimental Investigation of Productivity Improvement of Machining Process Using Multi-Tool Turning”** and Examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering.

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DECLARATION

I hereby declare that the work, which is being presented in thesis, entitled "**Experimental Investigation of Productivity Improvement of Machining Process Using Multi-Tool Turning**" In partial fulfillment of the requirement for the award of the Degree of Masters of Science in Manufacturing Engineering is my own work carried out September 2019 to June 2020 under the supervision and guidance of **Dr. Mo'era Gutu,** Program of Mechanical Design and Manufacturing Engineering, Adama Science and Technology University, Adama, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other Degree or Diploma. All relevant resources of information used in this thesis have been duly acknowledged.

Kuba Defaru Nedi	______________________	_____________________
Candidate	Signature	Date

This is to certify that the above declaration made by the candidate is corrected to the best of my knowledge and belief. This thesis has been submitted for examination with our approval.

Dr. Moera Gutu	___________________	____________________
Advisor	Signature	Date
Dr. Habtamu Berih	___________________	___________________
Co-Advisor	Signature	Date

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ABSTRACT

Machining is a widely used manufacturing process where some part of material is removed from bulk workpiece in the form of chips. In this thesis work, explores the science of new techniques of machining using two single point cutting tools simultaneously engaged with workpiece material to increase productivity of the turning process. In order to perform a double tool turning process, a conventional lathe machine was modified. In turning process the process parameters which affect surface quality of machined component are cutting speed, feed, and depth of cut. Experimental investigation was carried out to improve productivity by this new machining technique under the influence of cutting parameters on cutting temperature, dimensional error, tool wear; material removal rate and surface roughness. The chip morphology and machining time were also studied. An analytical analysis was done for single and double tool turning process based on ductile fracture mechanics approach and experiments were also carried out on mild steel. The analytically predicted cutting temperature, dimensional error, cutting tool wear, surface roughness, material removal rate, machining time, production rate were investigated in detail. For the selected cutting parameters of experimental result, it was observed that the material removal rate increased by 20%. A better machined surface obtained by double tool turning than using a single tool turning method. In this work, cutting parameters (cutting speed, depth of cut and feed) were optimized for both double and single tool turning process using Taguchi Method. The average surface roughness for single and double tool turning were 1.76 μm and 1.25 μm respectively. It was also surprising that material removal rate increased and machining time reduced by 25% in case of double tool turning. Tool wear area measured by optical Profilometer shows that total wear zone 813.11087 mm^2 for single tool turning while it was reduced to 45.57 mm^2 for double tool turning.

Keywords: Cutting temperature, Dimensional error, Tool wear, Surface Roughness, Material removal rate, Machining Time, Production rate.

ACRONMYS

AA	Arithmetic Average
ABMI	Akaki Basic Metal Industry
AISI 4340	Mild Steel
ANOVA	Analysis of Variance
ANSI	American National Standards Institute
C45	Low Carbon Steel
CLA	Center-line Average
d	Depth of Cut
D_{avg}	Average Diameter
D_i	Final Diameter
DOE	Design of Experiment
DOF	Degree of Freedom
D_o	Initial Diameter
f	Feed
F_c	Cutting Force
fr	Feed Rate
ISO	International Standardization Organization
MRR	Material Removal Rate
MSE	Mean Square Error
N	Spindle Speed
OA	Orthogonal Array
OM	Optical Microscope
P_{net}	Net Machine power
Ra	Average Surface Roughness
S/N	Signal to Noise
SST	Total Sum of Squares
SSTR	Treatment Sum of Squares
t_{active}	Active Time
t_{ct}	Tool change Time
t_{load}	Load and Unload Time
t_{total}	Total Time
V_C	Cutting Speed
σ	Standard Deviation or Variance

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CHAPTER-1

INTRODUCTION

1.1 Background of the Study

Metal turning process has been studied for more than a century and it is the most popular and industrialized machining process to remove the un-desired material from a work piece surface in both traditional and non-traditional manufacturing industries. Many metal cutting processes like turning, drilling, boring, milling, broaching etc., are widely used in industries to achieve the desired objectives. Among the various metal cutting processes, turning is widely used for machining the rotating surfaces through application of a single point cutting tool. Multi-tool turning process was identified as an effective machining to improve productivity was discussed by Lal GK (1996) and Saini M, et al. (2015). The cutting tool penetrates the work piece causing removal of material in the form of chips as the result of plastic deformation, shearing and rupture. Yildiz AR et al. (2012) examined the main objectives of the turning process including reducing the diameter to a specified dimension and producing a desired surface finish. Moreover, turning process can be used to produce complex and difficult profiles like gears, cams, shafts, axles etc., through application of special attachments as explained by Grzesik W et al.(2008).

Considerable amount of investigations on tool vibration has been carried out in the conventional manufacturing process by D.R.Salgado et al.(2006). Risbood et al. (2003) predicted surface finish and dimensional deviation of the turning process by considering the radial vibration of tool holder. Mehta N.K.et al. (1983) investigated the interaction between the tool wear and the vibrations of face milling process. Orhan et al. (2007) investigated end milling process and observed the relationship between the cutting tool displacement, velocity and acceleration with cutting tool wear. It is observed from the above literatures vibrations signals have been effectively used to monitor and predict the tool wear. However, there was no attempt made to understand the dynamics of multi-tool machining and present work attempt the same.

Very few research works on multi-tool machining process has been done so far which are discussed as follows. In multi-tool operations McCullough, E.M. (1963) determined the tool life for minimum cost and maximum production rate in which the total cycle time was controlled by the spindle speed. The tool failure patterns in multi-tool machining were investigated by A.Zompi et al. (1979) and the probability theories were used to assess the tool life. G.L.Ravignani et al. (1979) calculated tool life distribution by taking into account the sudden tool fracture and gradual tool wear. Sheikh et al. (1980) suggested different tool replacement conditions for single tool and multi-tool production machines. The effect of tool change policies over the cutting conditions was enumerated.

Tang et al. (2008) used particle swarm optimization based novel heuristic algorithm to optimize the process parameters for two-tool parallel turning operation. Ozturk and Budak(2010)modeled dynamics of parallel turning operation under two conditions. Cutting capacity of the parallel turning process found to be higher than turning with single tool. Ozturk and Budak(2011)also investigated dynamic interaction of two tools while cutting same surface. The model prediction was compared with the experimental results and found to be in good agreement. From the prior work it is clear that there is no attempt made to understand the effect of process parameters of multi-tool turning over cutting tool vibration. In this work, an attempt has been made to understand cutting speed, and offset distances over vibration behaviour of both the front and rear cutting tool in the multi tool turning process.

The technology of metal cutting has grown substantially over time owing to the contribution from many branches of engineering with a common goal of achieving higher machining process efficiency. Selection of optimal machining condition(s) is a key factor in achieving this condition (Tan & Creese, 1995). In any multi-stage metal cutting operation, the manufacturer seeks to set the process-related controllable variable(s) at their optimal operating conditions with minimum effect of uncontrollable or noise variables on the levels and variability in the output(s). To design and implement an effective process control for metal cutting operation by parameter optimization, a manufacturer seeks to balance between quality and cost at each stage of operation resulting in improved delivery and reduced warranty or field failure of a product under consideration. In a turning operation, the diametral error is the deviations between desired and the actual diameter of the work piece. This deviation is significantly influenced by the work piece deflection due to cutting force and radial force. In double tool turning process, the presence of rear cutting tool generates radial cutting force component which reduces the effect of the radial force component of the front cutting tool.

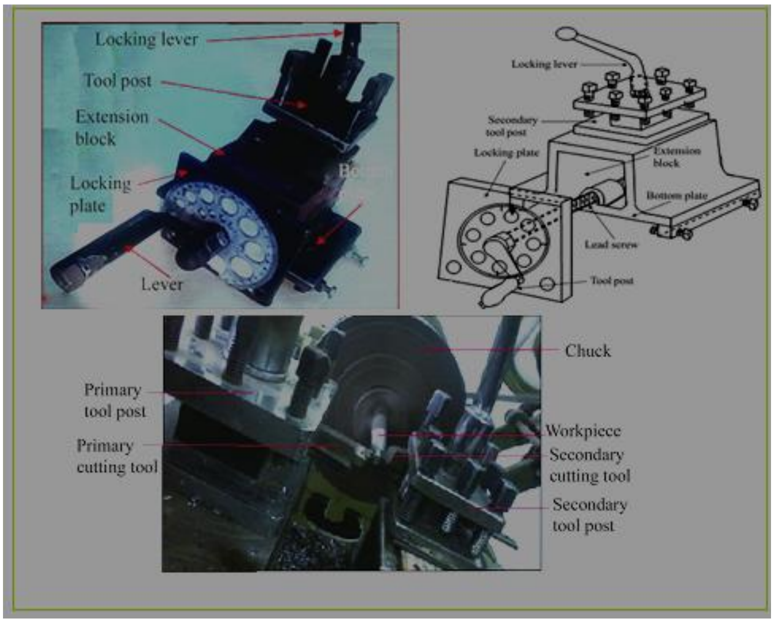

Figure 1.1 Double Tool Turning process (Ravindra Nath Yadav)

. The rear cutting tool also acts as a follower rest, which results in decrease in diametral error. This is one of the main advantages of this process. Phan et al. (2002) presented an improved model for predicting diametral error in turning and validated with experiments. The model takes into account the stiffness of the components that hold the work piece. Killic et al. (2007) developed a model for estimating cylindricity in turning that depends on the feed, radius of the work piece and the rake angle of the cutting tool. Machining experiments were conducted at various feed rates and cutting speeds to validate the developed model.

Carrino et al. (2002a, 2002b) developed a numerical model to evaluate the machining accuracy. The dimensional errors in turning experiments were measured to validate the developed model. Kops et al. (1993) developed a model to evaluate the accuracy of slender work pieces by considering radial forces and changing geometry. Jianliang and Rongdi (2006) developed a model for diametral error of the bar turning with a follower rest and compared it with the experimental results. Mayer et al. (2000) predicted the diametral error by incorporating the coupling between the cutting force and actual depth of cut. Benardos et al. (2006) predicted work piece deflection by considering discretized segments and compared it by correlating the measured diameter of the work piece after machining. Risbood et al. (2003) developed an artificial neural network model to predict the dimensional deviation of slender jobs in cylindrical turning.

Shashikant et al. (2013) investigated the chip segmentation, while machining titanium alloys at elevated temperature (100–350°C). Katuku et al. (2009) studied tool wear, cutting forces and chip characteristics when dry turning austempered ductile iron with polycrystalline cubic boron nitride cutting tool. It was observed that flank wear and crater wear were the main wear modes. At higher cutting speeds, abrasion wear and thermally activated wear were observed as the major wear mechanism.

1.2 Principle of Machining

Figure 2.1 typically illustrate the basic principle of machining. A metal rod of irregular shape, size and surface is converted into a finished product of desired dimension and surface finish by machining by proper relative motions of the tool-work pair.

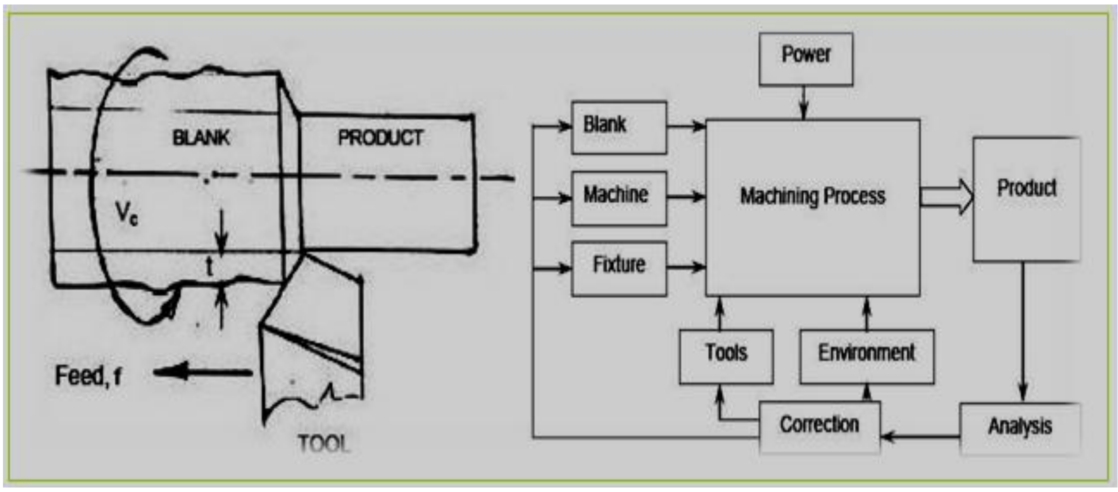

Figure 1.2 Principle of machining (Turning) and Requirements for machining

1.2.1 Concept of Multi-Tool Turning

The concept of multi tool turning is to use two single point cutting tools rather than one for turning the same shaft. The second tool should be mounted on the additional tool post. The additional tool post is fitted on the same carriage, and mounted on the same lead screw as the first one. It is noted here that to mounting the second tool post on the same lead screw is the most important step in the process. Figure 1.3 shows the schematic representation of the two tools working simultaneously on the single work piece. The research papers on the multi-tool machining are very less in comparing to conventional turning process, even though it offers ample scope of increasing the productivity. Researchers in the past had focused mainly on the optimization of process parameters in multi-tool machining.

Recently, the mathematical model was developed and cutting parameters were optimized the in duplex turning process using a combined Taguchi-Response Surface Methodology hybrid approach. It was reported that the surface finish improved significantly in hybrid approach compared to Taguchi method. From the available literature, it is seen that very little work has been done on the aspect of cutting forces, cutting tool vibration, surface roughness, dimensional error and cutting temperatures generated in the individual tools during simultaneous engagement during multi-tool machining/turning process. In multi-tool turning the depth of cut is shared among the number of tools. This reduces the cutting forces acting on individual tool. Hence it improves the machining accuracy and reduces the surface roughness. The next section deals with the cutting force, cutting temperature and tool wear aspects in machining, for single tool turning process. The literature survey on single tool turning process helps in setting the research direction for multi-tool turning process.

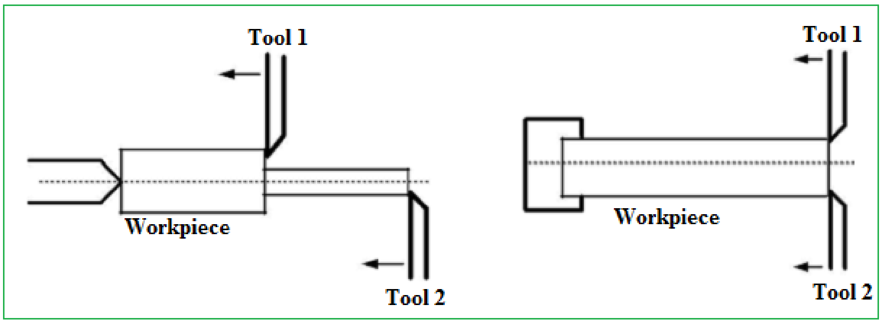

Figure 1.3 Schematic representation of multi tool turning

1.2.2 Cutting Forces

In conventional turning, three force components are involved. The vertical force is the main cutting force (F_c) which acts along the cutting direction. The feed force (F_f) acts in the direction of feed and the radial force component (F_r) acts in the radial direction of the work piece. The radial force component is also known as passive force. Cutting forces are measured either by strain gauge type dynamometer or piezoelectric type dynamometer. Recht (1985) analyzed the machining of 4340 steel using a tungsten carbide tool coated with titanium carbide. It was shown that the Merchant's classical equation based on minimum work approach as applied to machining at low speed is also applicable to machining at high speed. It was observed that with increase in speed from 242 m/min to 2121 m/min the friction coefficient (μ) decreases from 0.6 to 0.26. This is because of high heat generation which causes the asperities in the chip to melt. Apart from this, high temperatures are generated, which leads to rapid tool wear creating a crater which modifies the flank wear directly. Sutter et al. (1998) conducted metal cutting experiments to determine the cutting forces. It was observed that the cutting forces decreased with the increase in cutting speed. The reduction in friction coefficient is the main cause for reduced cutting forces. The experiments were conducted at both low and high cutting speeds. Ren and Altintas (2000) determined the cutting forces and cutting temperature in the deformation zone. Mold steel and carbide tool was used as work material and cutting tool respectively.

Yigit et al. (2008) investigated experimentally the machining of nodular cast iron with a coated carbide tool at various cutting speeds. The cutting forces decreased on increasing the cutting speed. The cause for a drop in Cutting force was attributed to the reduction in the yield strength of the work material.

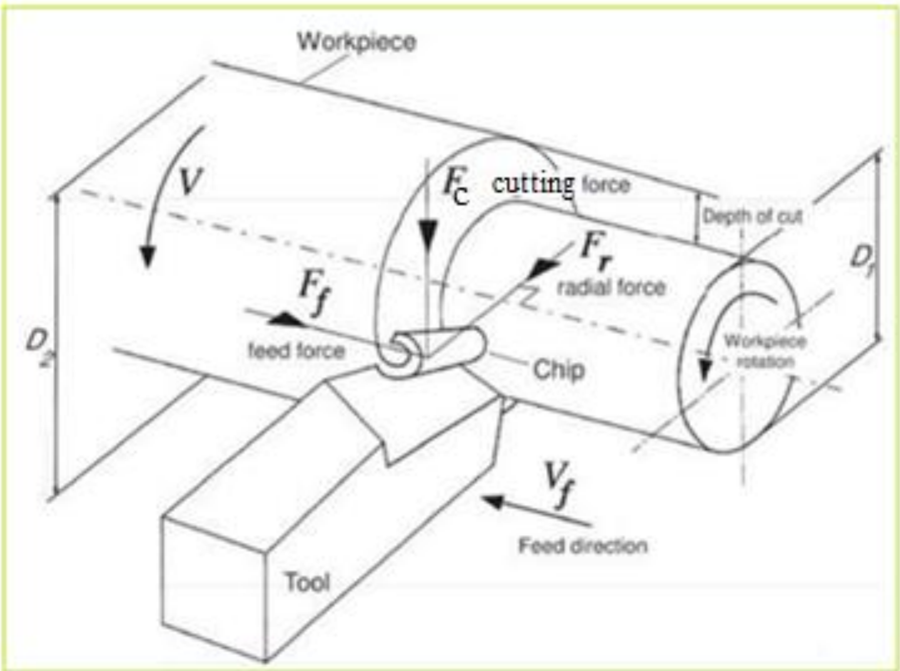

Figure 1.4 Schematic representation of turning Cutting Force

1.2.3 Cutting Temperature

In metal cutting operation the heat is generated in the cutting region. There are three main zones in the cutting region. They are primary, secondary and tertiary shear deformation zones. The heat generated in the primary shear deformation zone is due to the plastic deformation of the work material. The friction between the rake face of the tool and chip causes heat generation in the secondary shear deformation zone whereas the friction between tool flank and the machined surface causes heat generation in the tertiary shear deformation zone. The cutting temperature rises because of the heat generation in the cutting zone. Higher cutting temperature adversely affects the tool life. It decreases the wear resistance and hardness of the cutting tool. It also increases the tool wear thereby reducing the tool life. Higher cutting temperatures also cause poor surface finish and dimensional inaccuracy of the machined surface. Therefore it becomes important to maintain lower cutting temperature during the machining process. The cutting temperatures are measured by thermocouples, radiation pyrometers, and thermal paints.

1.2.4 Tool Wear and Tool Life

Tool wear is defined as the loss of material from the cutting tool surface. The cutting efficiency essentially depends on it. Crater wear and flank wear are the two main classes of tool wear. The former occurs on the rake face while the latter occurs on the flank face of the cutting tool. Tool wear is also caused due to micro-chipping, oxidation and diffusion. At low cutting speed and feed abrasion wear is predominant while at higher cutting temperatures oxidation and diffusion wear becomes predominant. Direct and indirect methods are utilized to measure the tool wear. Scanning electron microscope, optical microscope, confocal laser scanning microscope and stylus profilers are used in direct methods. While cutting forces, cutting temperature, tool vibration, acoustic emission and surface roughness are measured to evaluate the tool wear in indirect methods. The tool life crucially relies on tool wear. Tool life is the time period of machining during which the cutting tool delivers a desired and satisfactory performance. Higher tool life leads to higher productivity and decreased machining cost. The apparent manifestations of cutting tool wear are higher surface roughness of the machined work surface, increased magnitude of cutting forces due to loss of sharpness of the cutting edge and dimensional inaccuracy of the machined work piece. In machining the tool wear and tool life depends mainly on the following factors:

- The material of the machined component
- Cutting tool material and its shape
- Cutting conditions
- The machining process

Two main types of wear are abrasion wear and adhesive wear. When cutting at conventional speeds abrasion wear dominates.

1.3 Surface Roughness

Surface roughness is an important factor that determines the quality of a machined surface. It depends on many parameters such as cutting condition, machine tool vibration, cutting tool and work holding devices. The cutting speed, feed and depth of cut have a major influence on the surface roughness of the finished component. A lot of research work has been directed towards improving the surface quality of the machined component. Some relevant literatures are;

Sarma and Dixit (2009) conducted metal cutting experiments and compared the surface roughness produced by dry and air cooled turning of grey cast iron. It was observed that the air cooled turning process reduced the surface roughness and increased the tool life. Nalbant *et al.* (2009) investigated experimentally the effects of different types of inserts and cutting parameters on the surface roughness of steel. It was found that coated carbide inserts provided surface finish superior to uncoated carbide inserts. Correia and Davim (2011) performed experimental studies on AISI 1050 steel with conventional and wiper cemented carbide inserts. It was manifested that the wiper inserts surpassed the conventional inserts and produced superior surface finish even at higher feed. Ramesh *et al*. (2012) determined experimentally the effect of cutting parameters on surface roughness while turning titanium alloy. It was declared that the feed was the most influential factor affecting the surface roughness.

Gunay and Yucel (2013) estimated the average surface roughness of white cast iron while turning with ceramic and cubic boron nitride tools. It was established that cutting speed and feed significantly affected the surface finish of the machined surface. Apart from these experimental studies, many researchers (Choudhury and El-Baradie, (1997); Lu, (2008) predicted the surface roughness in turning. Many soft computing techniques such as neural network, fuzzy logic, genetic algorithms and hybrid network and response surface methodology were used for predicting the surface roughness.

1.4 Dimensional Error

In turning, dimensional error refers to the deviation between the actual dimension and the desired dimension of the work piece. It is one of the important attributes of the machined product. The cutting forces generated during turning causes the work piece to deflect which results in machining error. The machining error also depends on the rigidity of the machine tool and its vibration level. Reduction of dimensional error leads to improved machining accuracy. Kops *et al.* (1993) formulated an improved analysis of estimating the work piece accuracy based on the emerging diameter. It was stated that the effect of depth of cut is more dominant for slenderness ratio greater than 6. Investigations revealed that for lower slenderness ratio, the maximum deflection occurs at tailstock and for higher slenderness ratio it is at 60% of work piece length from the headstock. Phan *et al*. (2002) developed a new model using FEM to compute the work piece deflection. All the three force components and three usual methods of mounting the work piece on a lathe are taken into account. Closed form finite element solutions are derived, which is a function of the cutting tool position.

1.5 Chip Formation

Chip formation and effective chip removal are important in those cutting techniques in which the cutting zone is spatially limited, such as drilling, reaming, milling and all turning operations on automatic lathes. The details of chip formation process can be most readily seen using the orthogonal cutting model. In the orthogonal model, chip formation is considered to occur as a two-dimensional process in a plane perpendicular to the cutting edge.

During the machining process, the cutting tool penetrates the work material, which deforms first elastically and then plastically. As soon as the shear stress induced by the tool reaches or exceeds the shear strength of the work material in the shear zone, the material begins to flow. Depending on the tool geometry used, the deformed work material forms a chip that flows across the face of the cutting tool. Friction between the contact planes of the tool and the underside of the chip or the new workpiece surface creates shear stresses in the secondary shear zones. Generally, four main types of chip can be formed:

- Continuous chips,
- Continuous segmented chips,
- Semi-continuous segmented chips and
- Discontinuous chips.

Continuous chips form when the material is cut flows away continuously from the machining point. The regions of deformed material undergo lamellar sliding but without exceeding the shear strength of the material. If the work material being machined is of sufficient ductility, the chip formed will usually be continuous in form, provided that the cutting process is not impaired by the influence of external vibrations. If the workpiece material is of lower ductility, if it has an inhomogeneous microstructure or if it is subjected to external vibrations, machining will result in the formation of continuous segmented (or serrated) chips. Compared with continuous chips, the upper surface of the chip in this case exhibits a pronounced saw tooth-like structure. Continuous segmented (or serrated) chips can form at high feed rates and at high cutting speeds. Semi-continuous segmented (or serrated) chips, on the other hand, consist of chip sections that were completely separated in the shear zone. This type of chip forms when the degree of deformation in the shear zone exceeds the material's ductility. Discontinuous chips typically form when brittle materials with an inhomogeneous microstructure are machined. These chips are not cut but rather torn from the surface of the work material, with the result that the workpiece surface is frequently damaged by these small chip fragments

From the literature survey on multi-tool turning, it is observed that no experimental work has been carried out to understand the multi-tool turning process with respect to machining quality. The effect of the work piece slenderness ratio, cutting forces and follower rest on diametral errors was well understood. However, there has been no attempt to understand the effect of the double tool turning over the diametral error in turning. This work attempts the same by turning a cylindrical work piece with two cutting tools mounted on the same carriage. It is well understood that considerable work on chip morphology and tool wear has been carried out in turning operation to understand the mechanism of cutting. However, no work has been carried out to understand the cutting mechanism in the double tool turning with the aid of tool wear and chip morphology.

1.6 Motivation of the Work

A lot of researchers have carried out experimental investigations in Machining process to add some economical values, using some modification on different machine parts. From the various works carried out in the field of Multi-tool Turning, some of the gaps identified are listed as follows:

- Additional Cost for Design and Manufacturing of primary and secondary tool holding and tool post.
- The machining performance depends on several parameters. Among them the cutting forces and temperatures generated during process are of prime importance. In this aspect a lot of research work has been done on single tool turning process but Multi-tool turning process still needs to be explored.
- Using of two tools simultaneously improves the product quality in double tool turning process. The diametral error and the tool wear in double tool turning is another domain where there is hardly any documented research work. It offers an ample scope to explore it.

- Surface roughness in Multi- tool turning is an area that has receive great attention in spite of its ability to produce good surface finish.
- Machining Time role in the improvement of productivity in Multi-tool turning process is also an important gap which needs to be explored.

After identifying the gaps listed above, the experimental Investigation work has been proposed on Multi-tool turning process with redesign of the existing Tool holder to accommodate Multi-tool single point tools to improve the productivity by reducing the machining time, increasing Tool life with optimum temperature generation and surface roughness.

1.7 Statement of the Problem

Traditionally, many machinists think that improving productivity is maintained by increasing cutting speed, depth of cut and more feed rate. The inverse is true, because increasing those parameters affect tool life and maintain poor surface finish. The concept of improving productivity rather to focus on different ways like using more cutting tools engaged simultaneous on cutting. This method was started few years back by researchers while the modification and effectiveness need more experimental investigation. Single point tool turning process of components; results in higher consumption of production time, lower production rate; poor tool life, more materials consumption and less material removal rate. So, Multi-tool turning process is an important process which can solve above listed problems. Multi-tool turning process will be carried out on conventional lathe machine with necessary modifications. The experiments will be designed with the help design of experiment (DOE) tool.

The experiments on conventional lathe machine have been carried out as per the experimental design using Taguchi method L_9 orthogonal array. The mathematical modeling and optimization of process parameters have been carried out using Response Surface Methodology. The proposed work is expected to enhance the productivity and surface finish to a high level and this will help the scientists, researchers and industrialist in the field of metal machining.

1.8 Significant of the project

The proposed work is expected to help industries and researchers in the field of metal machining with double tool turning process. Productivity of the industries is expected to get enhanced through several folds. Lot of materials, energy and cost will be saved leading to improved socio economic impact on the nation. The concept of proposed work can be extended to further studies on machining like difficult to cut materials, composite machining etc. which will help the students and researchers in this field.

1.9 Scope of the Study

This study is bound to reduced machining cost compared to conventional turning process, hence it is advantageous is with respect to saving material, energy and tool life. An analysis of reduced machining cost will be limited to multiple cutting tools like double tool turning.

1.10 Research Objective

1.10.1 General Objective

The aim of this thesis work is to improve productivity of turning process using double tool turning method in conventional machining with the optimized process parameters.

1.10.2 Specific Objectives

The Investigations of machining performance dependents on several parameters where the specific objectives of this thesis are listed as follows:

- To design and manufacture of jigs and fixtures for multi tool holding on conventional lathe machine.
- To determine the productivity in multi tool turning process while maintaining the required quality of surface finish.
- To determine tool life, tool wear, temperature generation and machining time in multi tool turning process.
- To optimize the cutting parameters (speed, feed, depth of cut) to maintain optimum productivity using Taguchi's Method.

1.11 Limitation of this Thesis

The thesis on the Productivity Improvement of Machining Process Using Double Tool Turning is limited due to different challenging problem. The machine utilized for this experimental work is conventional lathe machine with necessary arrangements such as tool post, tool holding device/fixture and test equipments such as Dynamometers and

Accelerometers. Measuring Cutting Force was possible to know its influence on the Productivity Improvement. In contrast, keeping cutting Force rate constant or varying it was impossible due to Energy Consumption. Consequently, the cutting Forces rate was provided by using the machine via constant motion of the spindle. As a result, exact load utilized is not determined and made the research work more difficult. In addition, the other important instrument expected to use was accelerometer, which used to measure tool Vibration history during machining and this instrument was not used during the manufacturing process. Due to this, the experimental investigation was performed through Partial trial and error. The other main problem encountered during Productivity Improvement of Machining Process Using Double Tool Turning on lathe machine was preparation/ manufacturing of Fixture/Cutting Tool Holder.

1.12 Structure of the Thesis

The thesis consists of five chapters. Chapter one presents a brief introduction to the novelty of Experimental Investigation of Productivity Improvement of Machining Process Using Double Tool Turning. The statement of problem, significant, scope, objectives, and limitation of this thesis are also elucidated. Chapter two describes the general backgrounds about Multi-tool Turning process, the idea and the principle of Multi-tool Turning processing and a detailed literature review are presented. Related conventional single Turning process is also compared with Multi-tool Turning process.

Chapter three describes the general research design, material, tool design and manufacturing and experimental condition. In addition, the experimental setup and procedures as well as testing procedures are also explained in this chapter. Chapter four explains results and discussion obtained from experimental observations. Characteristics of production rate of single and double tool turning, macro and microscopically investigations, as well as quality of the product is extensively discussed. Finally, summary of the thesis outcome is stipulated in chapter five with the concluding remarks and provision of future works for further research directions.

CHAPTER 2

LITERETURE REVIEW

2.1 Introduction

In present era of economic development there is a great need for producing high quality machined components at reduced cost. This can be achieved by using sophisticated machine tools and decreasing the machining time. Some of the methods adopted to reduce the machining times are using higher operating conditions, performing many operations simultaneously, employing jigs and fixtures and employing computer numerical control machine tools. Higher cutting conditions in turning imply higher cutting speed, feed and depth of cut. Among the three parameters, increasing the cutting speed has got many advantages compared to the other two. This had led to the concept of high speed machining. Superior surface finish, higher accuracy, increased productivity, reduced tool wear and higher tool life are some of the advantages of high speed machining. Even though there are a lot of advantages, still certain inherent drawbacks persists when machining at high speed. Higher investment and maintenance cost, reduced tool life and higher tool wear rates are some of its demerits. Ultimately this has led the researchers to explore some other methods of improving the productivity. An alternate method of increasing the productivity is by engaging more tools at the same time to machine a component. It gives rise to multi-tool turning machining. Based on the literature review the research work carried out by various researchers in the field of multi-tool turning have been categorized into several issues as follows:

- Study of optimization of process parameters
- Study of Cutting forces
- Study of cutting temperature and heat generation
- Analysis of Surface roughness
- Analysis of tool wear
- Analysis of dimensional deviation
- Investigation of production rate and productivity
- Analysis of Material Removal Rate and productivity
- Investigation machining time and productivity

- Analysis of Chip Formation

2.2 Feasibility of Multi-tool Turning

In present day scenario, in modern industry the goal is to manufacture low cost, high quality products in short time. So in order to full fill the above mentioned goal, one has to focus on Multi-tool turning machining which maximizing of material removal rate and minimizing of machining cost method which will enhance the production rate by minimizing the machining time and at the same time will not affect the quality of the work finished. Analyze the effect of using this type of additional single cutting tool on the overall performance of the machine. i.e. on Production rate, machining time, tool life, Cutting Temperature, surface finish etc. The application of Multi-tool machining is normally attempted; in the application of this the machining time reduction, minimized the machining cost per part and the maximum production rate of machine tools; because the Multi-tool operates simultaneously.

The main aim of this work is to make an experimental study on the production improvement (Rate) in the Multi-tool turning process, particularly with reference to two single point cutting tools machining simultaneously, which plays the most important parameters of the economics of machining and the maximum production rate of tools; which of those parameters is more important depends on many factors. Manufacturers are struggling to increase of productivity of machining processes and to produce the next generation highly functional structural components for delivering infrastructure and expand to other markets and applications. According to available literatures, Very few of the research work is concentrated on Multi- tool turning owing to its industrial applications, production quality's, significantly reducing energy consumption and it eliminates more machining time per parts.

2.3 Optimization of Machining Process Parameters

B. Y. Lee (1999) carried out optimal selection of cutting parameters considering the economics of multistage turning operations. Polynomial networks have been used to construct the machining model for multistage turning operations. The sequential quadratic programming method is then applied to the networks for searching optimal cutting parameters with maximizing the production rate or minimizing production cost. Practical examples in multistage turning operations are presented to illustrate the approach proposed by this study.

Tang *et al.* (2008) studied a novel heuristic algorithm based on Particle Swarm Optimization (PSO) to optimize the process parameters for two-tool parallel turning operation. PSO provided the optimum solution in less computational time. El-Hossainy (2010) developed a turning tool having two cutting edges. It was proclaimed that new tool reduced the surface roughness, straightness and roundness errors by 58, 65 and 50 percentage respectively, for a particular machining condition. Budak (2011) studied the dynamics and stability of parallel turning process in time domain and frequency domain. An improvement in process stability was obtained due to the interaction between two cutting tools. An analytical model was constructed and the experimental results were matched with the results of the analytical model.

S. K. Deepak (2012) in his research paper, the cutting speed and feed rate were modeled for the minimum production time of a turning operation. The maximum cutting speed, the maximum feed rate, maximum power available and the surface roughness was taken as constraints. The results of the model show that the proposed method provides a systematic and efficient method to obtain the minimum production time for turning. This approach helps in quick analysis of the optimal region which will yield a small production time rather than focusing too much on a particular point of optimization.

Ozturk *et al*. (2016) predicted the stability limits in parallel turning process for two different cases. It was concluded that most stable conditions are obtained when the natural frequency of the two cutting tools are slightly different from each other. On the other hand, poor stability occurs when the two cutting tools have exactly the same natural frequency. Recently Yadav (2017) developed a mathematical model and optimized the cutting parameters in duplex turning process using a combined Taguchi-Response Surface Methodology hybrid approach. It was reported that the surface finish improved significantly in hybrid approach compared to Taguchi method.

2.4 Analysis of Cutting forces

One of the most promising techniques for detection of cutting condition involves the measurement of cutting forces. Cutting forces are important to achieve its dimensional accuracy, and machining system stability. In all classical metal cutting procedures in the area of contact between tool and material appears a cutting force, which can be decomposed after three orthogonal components. In practice, the resulting value of the cutting force is less of importance, relevant being its components, which are used in calculations of fixing devices for the material, tools, resistance of the various parts of the machine tools, to calculate the propulsion power of the driving electric motors, and the calculation of processing accuracy. Moreover, the need for measurement of all cutting force component arises from many factors, but probably the most important is the need for correlation with the progress of tool wear. Three principal forces acting on a cutting tool during turning process are cutting force (F_c), thrust force (F_t) and radial force (F_r) as shown in the Figure 2.1.

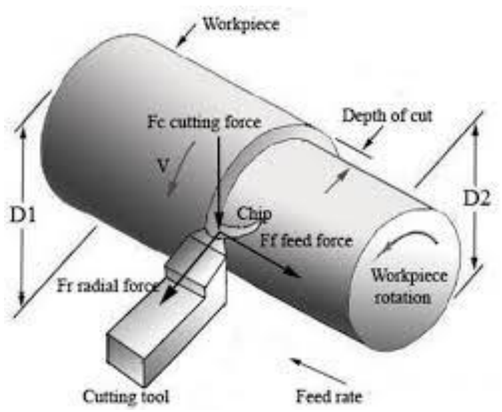

Figure 2.1 Schematic Representation of cutting force

The cutting force acts downward on the tool tip and thus tends to deflect the tool downward and the work piece upward and it supplies the energy required for the cutting operation during the process. Ratio of Fc to cross-sectional area being cut is called specific cutting force. The thrust force acts in the longitudinal direction. It also called the feed force because, it is in the feed direction of the tool and this force tends to push the tool towards the right and away from the chuck. These two forces produce the resultant force *R* and radial force acts on the cutting tool perpendicular to cutting force. The cutting force used in this study was calculated from equation (2.1) for the turning operation.

$$P_{net} = \frac{F_c{}^* V_c}{60000} \quad (2.1)$$

where, F_c= cutting force, P_{net} =net machine power in KW, V_C= cutting speed in m/min

2.5 Analysis of Cutting Temperature

Large quantity of material removed in short time causes higher heat generation in the cutting zone followed by a sharp rise in temperature. This heat which is concentrated near the cutting edge of the tool affects the cutting tool performance while machining.

Dewes *et al*. (1999) measured the temperature during machining of hardened mold/die steel by using both tool work thermocouple and Infrared camera. Interface temperature measured using the thermocouple when machining with the workpiece at 0 °C was between 200-300 °C. Cutting temperature increased with cutting speed and it did not reduce at higher speeds. Infrared technique indicated lower temperature than the thermo couple method with Value ranges of 68-390 °C.

A relatively low measured cutting temperature makes tungsten carbide to be used successfully for the high speed machining of hardened steels. Sutter *et al.* (2003) conducted experiments to measure the temperature fields while machining at high cutting speed. The tool and work material pair is coated carbide and alloy steel. Pyrometric technique (Infrared camera) for temperature measurement was used. It was concluded from the experiment that there exists a hot spot in the chip temperature distribution. This hot spot is located near the tool-chip interface at a distance of 300-350 µm from tool tip and the temperature is 825 °C. The chip temperature increases with increase in cutting speed and it is very dominant in the range of 20-30 m/s. The temperature stabilizes for cutting speeds greater than 40 m/s. With the increase in depth of cut the chip temperature increases following the same trends like cutting speed.

Karpat and Ozel (2008) presented analytical and experimental validation of a thermal model when machining at higher cutting speed with chamfered tools. The effect of cutting conditions, heat generation and resultant temperature distribution at the tool and in workpiece was investigated. The tool and work material pair is CBN and AISI 4340 steel. It has been observed that the temperatures increased with increasing uncut chip thickness. This also resulted in the decrease in friction factor. There are many detrimental effects of high cutting temperatures produced during machining. This further gets aggravated on increasing the cutting parameters such as cutting speed, feed and depth of cut.

2.6 Study of Surface Roughness

Surface roughness is an important factor that determines the quality of a machined surface. It depends on many parameters such as cutting condition, machine tool vibration, cutting tool and work holding devices. The cutting speed, feed and depth of cut have a major influence on the surface roughness of the finished component. A lot of research work has been directed towards improving the surface quality of the machined component. Some relevant literatures are; Sarma and Dixit (2009) conducted metal cutting experiments and compared the surface roughness produced by dry and air cooled turning of grey cast iron. It was noted that the air cooled turning process reduced the surface roughness and increased the tool life. Nalbant *et al*. (2009) investigated experimentally the effects of different types of inserts and cutting parameters on the surface roughness of steel. It was found that coated carbide inserts provided surface finish superior to uncoated carbide inserts. Correia and Davim (2011) performed experimental studies on AISI 1050 steel with conventional and wiper cemented carbide inserts. It was manifested that the wiper inserts surpassed the conventional inserts and produced superior surface finish even at higher feed. Ramesh *et al*. (2012) determined experimentally the effect of cutting parameters on surface roughness while turning titanium alloy. It was declared that the feed was the most influential factor affecting the surface roughness. Gunay and Yucel (2013) estimated the average surface roughness of white cast iron while turning with ceramic and cubic boron nitride tools. It was established that cutting speed and feed significantly affected the surface finish of the machined surface. Cakir *et al*. (2009) developed a regression model to estimate the surface roughness by considering both the cutting parameter and coating material of the cutting tool insert.

Table2.1 Center –line Average and Roughness Grades

R_a Values up to a Value in μm	Roughness Grade Number
0.025	N1
0.05	N2
0.1	N3
0.2	N4
0.4	N5
0.8	N6
1.6	N7
3.2	N8
6.3	N9
12.5	N10

Surface roughness most commonly refers to the variations in the height of the surface relative to a reference plane. It is measured either along a single line profile or along a set of parallel line profiles (surface maps).

It is usually characterized by one of the two statistical height descriptors advocated by the American National Standards Institute (ANSI) and the International Standardization Organization (ISO) (Anonymous, 1975, 1985). These are (1) Ra, CLA (center-line average), or AA (arithmetic average) and (2) the standard deviation or variance (σ), Rq or root mean square (RMS). Table 2.1. Roughness grading numbers and their *Ra* values. Adapted from (Bhushan, 2001). The higher the *N* number, the greater the roughness of the surface.

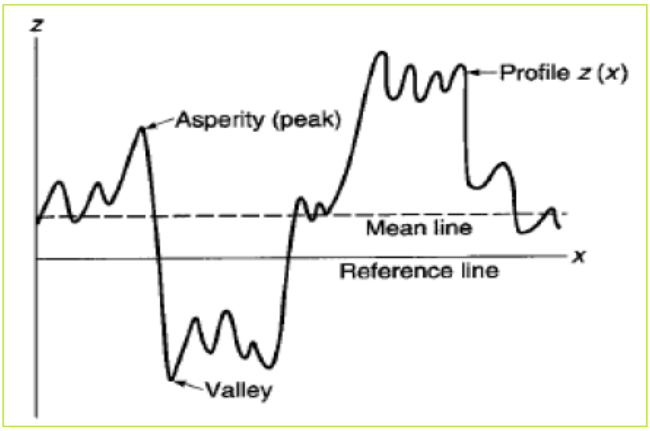

Figure 2.2 Surface roughness profile from the amplitude parameters (Bhushan, 2001)

2.7 Analysis of Tool Wear

The damages of a cutting tool are influenced by the stress state and thermal load on the tool surfaces, which in turn depend on the cutting mode, i.e. turning, milling or drilling, cutting parameters and the cooling/lubrication conditions. In machining, the cutting tool wear mechanisms and the rate of it are very sensitive to changes in the cutting operation and the cutting conditions. To minimize machining cost, it is not necessary only to find the most suitable cutting tool and work material combination, for a given machining operation, but also to reliably predict the tool life. Tool wear mainly occurs at rake and flank face. Flank wear is caused by friction between the flank face of the cutting tool and the machined work piece surface and leads to loss of the cutting edge. In machining the tool wear and tool life depends mainly on the following factors:

- The material of the machined component
- Cutting tool material and its shape
- Cutting conditions
- The machining process

Abukhshim *et al*. (2004) conducted an experimental investigation of the tool-chip contact length and wear in high speed turning of EN 19 steel with uncoated carbide tool. The cutting speeds ranging from 200 to 1200 m/min with feeds of 0.14 mm/rev and 0.2 mm/rev and a depth of cut of 0.1 mm was employed. The tool-chip contact length is found to increase for cutting speeds from 400 m/min to 1200 m/min. Sliding friction is common in conventional machining; at high speed machining seizure takes place and sticking friction occurs. Characteristic chip curl could account for a significant increase in the chip contact width observed in the case of high cutting speed. All these are applicable for high speed machining using uncoated carbide tools. For advanced PVD coated tools, contact conditions, temperature fields and tool wear are left for future investigation.

List et al. (2009) made an experimental investigation of tool wear in high speed machining by using a ballistic setup. The tool and work material employed was uncoated carbide insert and low carbon steel. The research findings show that the crater wear size increases with the increase in cutting time duration.

2.7.1 Tool Failure Modes

It is important to identify the different tool failure modes in order to select appropriate operating conditions for machining.

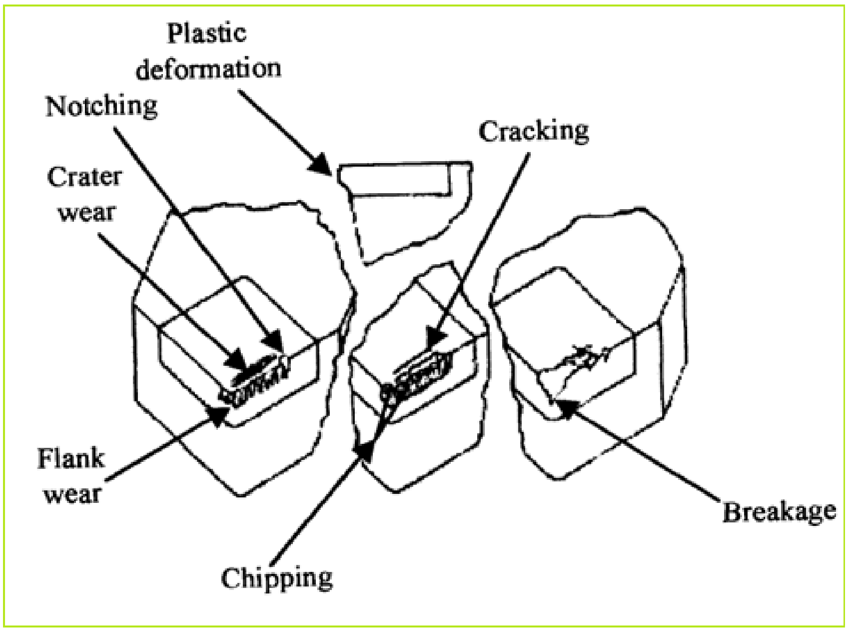

Figure 2.3 Tool Failure Modes

The most widely researched tool failure modes are flank wear, breakage (fracture), crater wear and plastic deformation .Other modes include notching (groove wear), cracking and chipping. Notching and chipping changes the tool nose curvature. Figure 2.3 displays the tool failure modes, as depicted.

Flank and crater wear are generally accepted as the normal tool failure modes, because the other failure modes can be avoided by selecting the proper machining parameters. The growth of flank and crater wear are directly related to the cutting time (or length of cut), unlike some of the other failure modes which can occur unexpectedly, even with a new tool.It is already well established that flank, Wear has the greatest influence on the work piece dimensions and surface quality. For this reason flank wear has been widely researched, and ways and means of predicting it has been the pursuit of researchers for many years. However, Multi-tool turning process has a potential to overcome these limitations and it would be interesting to explore it.

- **Flank wear**

Flank wear is the volumetric loss at the top of the tool tip edge, and is mainly caused by abrasion. It is of course normal that a tool will wear out at some or other stage, depending on the type of work it has been subjected to. Some authors affirm that the flank. Wear in coated tools first occurs due to abrasion, and, as the cutting process continues, the temperature also increases and diffusion also occurs Flank. Wear normally occurs at lower operating speeds.

- **Fracture**

Fracture is a mode of failure characterized by breakaway of material on the tool edge. Fracture occurs when the feed-rate is too high, or when a tool is used with too low fracture strength.

- **Crater wear**

Crater wear is a mode of failure predominantly caused by diffusion of tool material into the chip when operating at high speeds. The tool-chip interface temperature governs this mode of failure. This is in its turn a function of the speed and feed-rate.

- **Plastic deformation**

Plastic deformation starts when the temperature of the tool tip reaches a certain value. This implies that the tool yield strength is lowered below the existent normal stress. Further plastic deformation results in a temperature increase that causes complete failure. Keeping the temperature increase at the tool tip edge lower than a critical value can prevent this failure mode.

2.8 Study of Dimensional Deviation

One of the biggest problems faced in turning processes is the elastic deformation of the tool or in the workpiece. This deformation is because of to the cutting forces resulting in the radial direction being different than expected or simply uncontrolled.

This elastic deflection has to be specially controlled when machining with long and slender tools. These tools are more likely to experience deflection because of its structure. The ratio length/diameter is a relation between length and diameter is used to describe the slenderness of the tool.

In turning processes, the most important technical requirements refer to the dimensional accuracy and the finish surface quality of the produced part. This means that it is necessary to take control over the tool when it is experiencing this kind of elastic deflections. In order to accomplish it, the possible deflection that will suffer the tool has to be calculated.

Mayer *et al.* (2000) proposed a geometric analysis of the elastic deflections of the machine-workpiece-tool system due to the cutting force for predicting the diameter error. It was mentioned that both radial and axial cutting force component are significant. The tangential component of cutting force and the coupling between this force and the actual depth of cut is insignificant. Carrino *et al.* (2002a) proposed a new model to evaluate the machining accuracy and dimensional errors in bar turning. The deflections due to tool, workpiece and work holder was taken into account. The cutting forces were calculated based on unified generalized mechanics of cutting approach. In the second part the same authors, Carrino *et al.* (2002b) validated the proposed model through experimental tests. The workpiece clamped in a chuck, supported between two centres and clamped in a chuck and supported by a centre in the tailstock are the three conditions of workpiece fixturing that was considered in the experiments. A good agreement between the numerical model and experimental results was reported. Bodi,C.,& Rongdi, H. (2007) developed a model to predict the diametral error of slender bar. The model consists of geometric analysis of diametral error, finite element model of workpiece deflection and statistical model of cutting forces. It was concluded that the diametral error mainly depends on the location of the follower rest, depth of cut and feed.

2.9 Study of Production Rate and Productivity

As study conducted by Wang S-G and Hsu, (2005); Abburi *et al.*, (2007) showed the optimization of the single and multiple passes turning operations and others Authors are develop mathematical models that enable the calculating of the minimum machining cost depending on the changes in the machining modes and the optimization of the machining process Usubamatov.R., Zain, Z. M., & Ahmed, A. M. (2011).(Kalpakjian, 2006). However, the criterion of the maximum productivity rate of machinery prevails in many cases of industrial production. In this Experimental Investigation the mathematical models of the optimal machining modes for multi-tool machining processes with different cutters involved simultaneously and separately in processes. Mathematical models of optimization of machining mode considering maximum productivity rate criterion. Defined expressions of changes in the parameters of the productivity rate enable derivation of the equation of the productivity rate for machine tools with change in multi-tool machining mode when cutters imply simultaneous operations.

2.9.1 Material Removal Rate (MRR)

The material-removal rate (MRR) in turning is the volume of material removed per unit time or it is defined as a measurement from the initial and final weight of job. For each revolution of the workpiece, a ring-shaped layer of material is removed which has a cross-sectional area that equals the product of the distance the tool travels in one revolution (feed, f) and the depth of cut (d). The unit of material removal rate is $\left(mm^3/min\right)$ or $\left(in^3/min\right)$. The volume of this ring is the product of the cross-sectional area (f) (d) and the average circumference of the ring πD_{avg}

where $$D_{avg} = \frac{D_o + D_i}{2} \tag{2.2}$$

$$d = \frac{D_o - D_i}{2} \tag{2.3}$$

The rotational speed of the work piece is N and the material removal rate per revolution is $\pi D_{avg}(f)(d)$ since, there are N revolutions per minute, and the removal rate is given by:

$$MRR = \pi D_{avg} dfN \tag{2.4}$$

$MRR = dfV_c$, where V_c is the cutting Speed; $v_c = \pi D_{avg} N$

2.9.2 Machining Time

The total time, t_{total} to machine a part by turning has three contributions: the time t_{load} taken to load and unload the part to and from a machine tool; the time t_{active} in the machine tool; and a contribution to the time taken to change the turning tool when its edge is worn out. t_{active} is longer than the actual machining time t_{mach} because the tool spends some time moving and being positioned between cuts. t_{active} May be written t_{mach}/f_{mach}, where f_{mach} is the fraction of the time spent in removing metal. If machining N parts results in the tool edge being worn out, the tool change time t_{ct} allocated to machining one part is t_c/N. Thus

$$t_{total}=t_{load}+\frac{t_{mach}}{f_{mach}}+\frac{t_{ct}}{N} \tag{2.5}$$

It is easy to show that as the cutting speed of a process is increased, t_{total} passes through a minimum value. This is because, although the machining time decreases as speed increases, tools wear out faster and *N* also decreases. Suppose the volume of material to be removed by turning is written MRR then

$$t_{mach}=\frac{MRR}{fdv} \tag{2.6}$$

The machining time for N parts is N times this. If the time for N parts is equated to the tool life time T in equation (2.5) (generalized to $TV^n=C$), N may be written in terms of n and C, f, d, V_{vol} and V, as

$$N=\frac{fdc^{1/n}}{MRRV^{(1-n)/n}} \tag{2.7}$$

Substituting equations into equation

$$t_{total}=t_{load}+\frac{1}{f_{mach}fdv}\frac{MRR}{fdv}+\frac{MRRV^{(1-n)/n}}{fdc^{1/n}}t_{ct} \tag{2.8}$$

(According to Boothroyd and Knight, 1989)

2.10 Analysis of Cutting Parameters

The most important cutting parameters for turning operations are cutting speed, feed rate and depth of cut. Their definition is as follows with mathematical expressions. Cutting speed is one of the most important parameters in turning process and it is the speed of the workpiece surface relative to the edge of the cutting tool during a cutting process, measured in surface feet per minute or meter per minute. The rotational speed in turning is related to the desired cutting speed at the surface of the cylindrical workpiece during the process.

$$V_c = \frac{\pi DN}{1000} \quad (2.9)$$

where, V_c -Cutting Speed in m/min, N-Spindle Speed in rev/min and Do –outer Diameter in mm.Feed rate is the rate at which the tool advances into the work. The feed in turning is generally expressed in mm/rev (in/rev). This feed can be converted to a linear travel rate in mm/min (in/min) by the formula;

$$fr = Nf \quad (2.10)$$

where, f_r -feed rate in mm/min, N- spindle speed in rev/min and $f - \text{feed in mm/rev}$

Depth of cut is the amount of material removed as the work revolves on its axis. The turning operation reduces the diameter of the work from its original diameter D_o to a final diameter D_i as determined by the depth of cut d:

$$d = \frac{D_O - D_i}{2} \quad (2.1)$$

where, d-depth of cut in mm, D_O -outer diameter in mm, D_i -final diameter in mm

From the available literature, it is seen that very little work has been done on the aspect of cutting forces, surface roughness, dimensional error, Cutting Tool Wear and cutting temperatures generated in the individual tools during simultaneous engagement during multi-tool machining/turning process. In multi-tool turning the depth of cut is shared among the number of tools. This reduces the cutting forces acting on individual tool. Hence it improves the machining accuracy and reduces the surface roughness. The next section deals with the cutting temperature and tool wear aspects in machining, for single tool turning process. The literature survey on single tool turning process helps in setting the research direction for multi tool turning process.

With the development of new machine tools capable of higher material removal rate (MRR), the significance of machining at high cutting speed has increased tremendously at present. Nowadays machining is carried out in the range of 3 to 5 times higher than the conventional machining speeds. It leads to reduced processing times, improved work piece accuracy and surface integrity. Certainly there are some limitations too. The main performance parameters in a machining process are cutting forces, cutting temperature and tool wear. These factors determine the production costs, process efficiency and tool life.

2.11 Research Gaps

Researchers have been fascinated by metal cutting due to its economic and technical importance. Among all the machining process turning is a very widely used process. Many efforts have been directed towards improving the productivity of the process. A small increase in productivity can lead to large amount of cost savings. Multi-tool turning process has got many advantages apart from increasing the productivity. Therefore, the following aspects of multi-tool turning need to pay attention:

- *The machining performance depends on several parameters. Such, the cutting forces and temperatures generated during process are of prime importance. In this aspect a lot of research work has been done on single tool turning process. Double tool turning remains a less explored area.*
- Use of two tools simultaneously improves the product quality in double tool turning process. The dimensional error and the tool wear in double tool turning is another domain where there is hardly any documented research work. It offers an ample scope to explore it.
- Surface roughness in double tool turning is an area that has received inadequate attention in spite of its ability to produce good surface finish.
- Machining Time role in the improvement of productivity in Multi-tool turning process.

CHAPTER-3

MATERIALS AND METHODS

3.1. Introduction

The detailed methodology used for Experimental Investigation of Productivity Improvement of Machining Process Using Double Tool Turning is provided in this chapter. To investigate the impact of machining time, improve of productivity and study the behavior of cutting parameters for Mild steel bars via double tool turning machining process, tool holder and cutting tools were manufactured at Akaki Basic Metal Industry (ABMI) and the manufacturing process /the experiment was carried out at Haromsa machine shop using conventional lathe machine.

Phase One

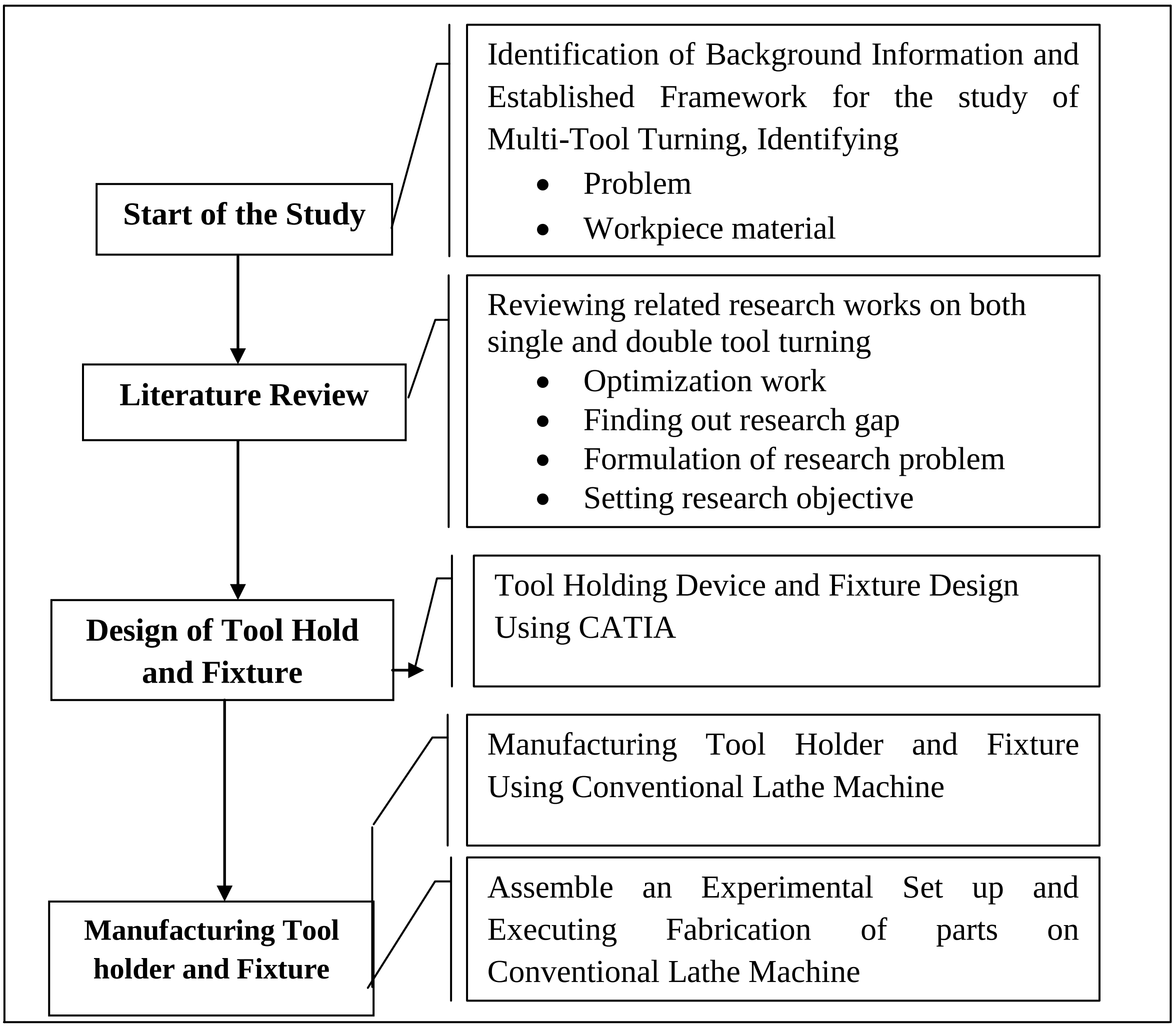

Figure 3.1(a) Phase one flow chart of the Methods

Phase Two

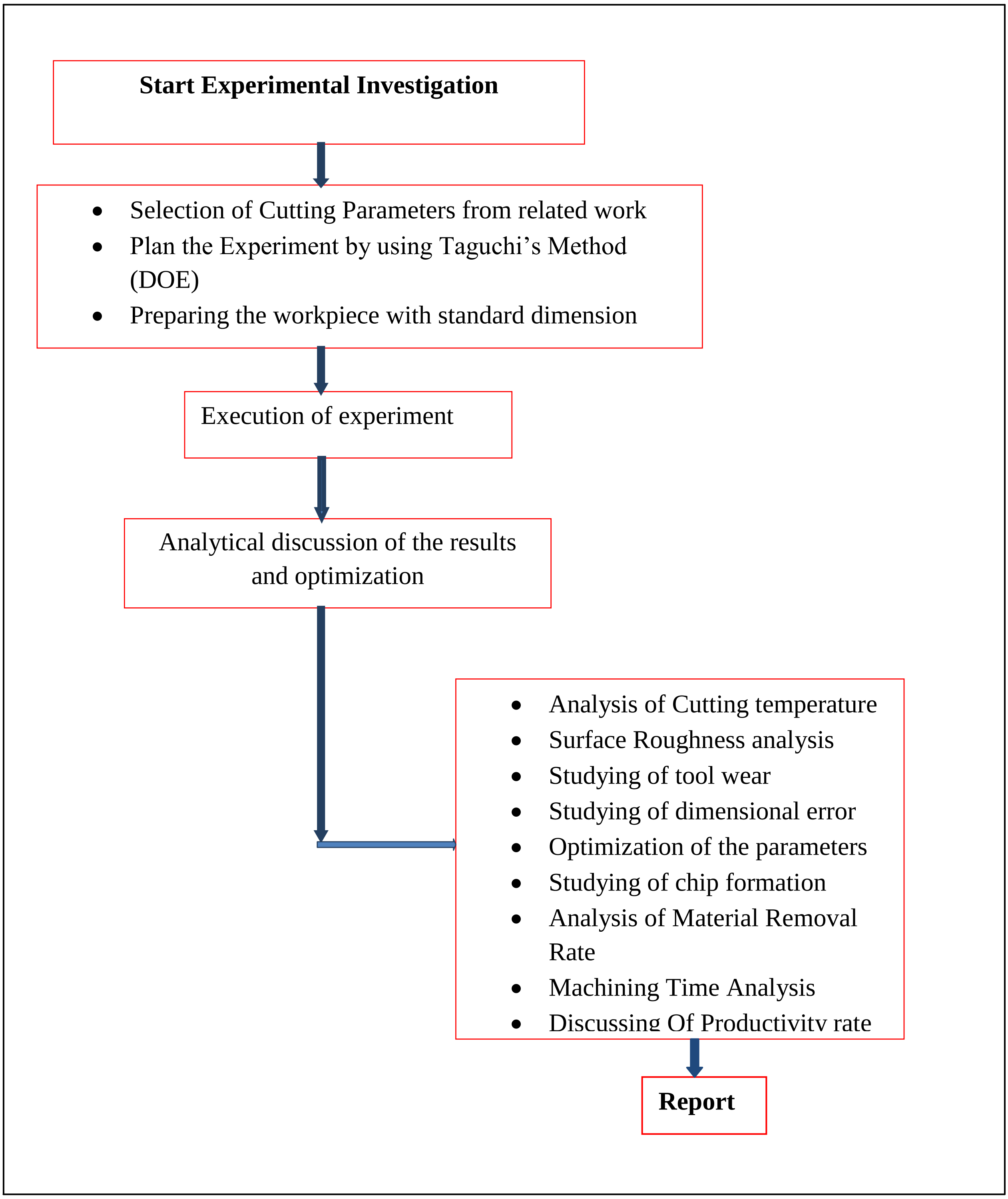

Figure 3.2(b) Phase two flow chart of the methods

In addition to experimental investigations, DoE analysis was carried out in order to optimizing different parameters of the machining process Using double tool turning and predict the cutting forces, cutting temperature, tool wear, dimensional error as well as surface roughness during single tool turning and double tool turning of the process.

Accordingly, to achieve the general objective of the research; the general research design is prepared as shown described in Figure 3.1(a) and (b). The experimental setup for the machining process consists of two major systems:

(a) Single cutting tool holding system

(b) Double Cutting Tool holding System. The issues that was considered during experimental works includes the process parameter based factors, method of temperature measuring, machining time measuring, production rate, Surface quality of the product is the critical aspects to be take care. The following section will introduce the double tool holding fixture designing and manufacturing, material, instrumentation, and machine modifications used in this work.

3.2. Tool Fixture Designing and Manufacturing

For this experiment, the tool fixture was manufactured using C45 steel heat treated to Rockwell hardness C of 40-55. The tool fixture has **(82*130*170)** dimension which is used for rigidly mounts on to the tool post of the lathe. The tool fixture has grooved part to the dimension of **37*75**, On the top side plate hole with **M14*2** on equal desistance each to fastening the cutting tool and holes at the center of the tool fixture with the dimension of Dia.=59,h =49,Dia.=48,h=33 from top to down, which fastening the tool holder to the tool post.

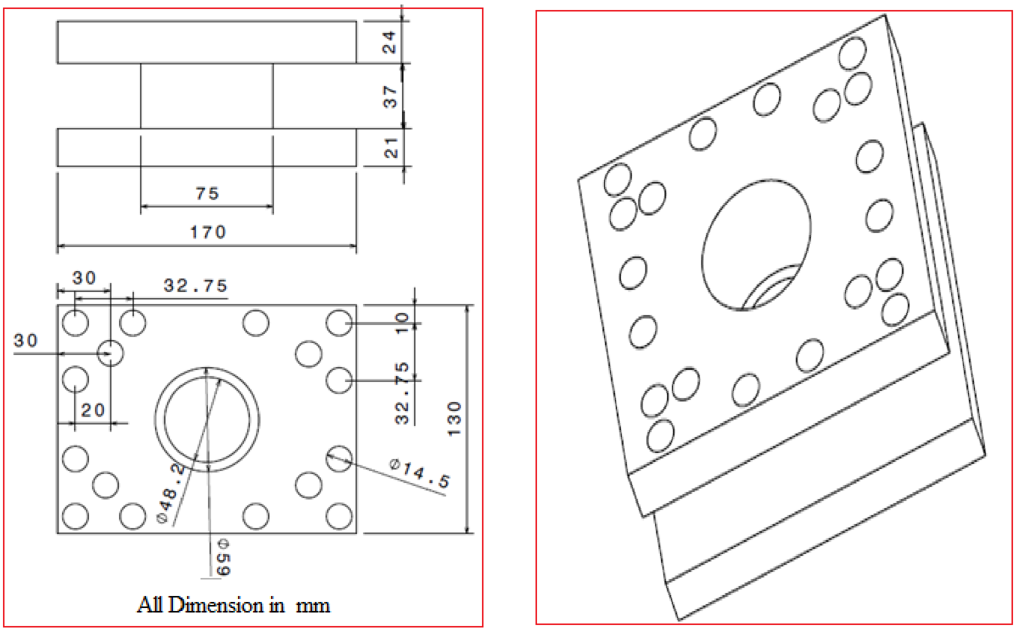

Figure 3.3.(a) Detailed schematic of the Tool Fixture

Figure 3.4. (b) Photo of the Tool Fixture

The manufacturing process of tool fixture was performed on lathe machine at Akaki Basic metal industry (ABMI). Harrison M 460 lathe (as shown in Figure3.3 was used to manually create the geometry from the round bar. It has an accuracy of 0.001 mm (1μm).

Figure 3.5 Harrison M 460 lath machine

Heat treatment was carried out to the tools to achieve high hardness and better wear resistance. According to the guideline provided by the supplier of the tool steel, the tool underwent hardening, quenching, and tempering procedure to achieve hardness of HRC 45 as referred in Table 3.1.

Table 3.1 Guide line for heat treating C45 tool steel

Hardening temperature	Soaking time	Quenching media	Tempering	Rockwell hardness
820-850 ℃	Soaked at temperature 10-15 minute for each 25mm section and quenched in water or brine	Water	400℃	35-45 HRC

3.3. Cutting Tool Holder and Fixture Modifications

The double tool turning process was carried out on a conventional lathe machine fit with an attachment modified to accommodate required experiments. The lathe machine Tool post was used to mount the tool fixture at the right position. The double single point Cutting tools were mounted on the manufactured tool fixture as shown in Figure 3.4.

Figure 3.6 Lathe machine configurations

3.4 Materials and Composition

Materials used for this study is AISI **1018 Mild Steel Rods** which are highly applicable in application of Space spare parts, gears, pinions, bolt and nuts, high speed screw machine parts etc. Mild Steel material consists of C 0.14-0.20%, Fe 98.81-99.26%, Mn 0.6-0.90%, S$\leq$0.050%, P$\leq$ 0.040% elements weight percentage. **Mild Steel Rods** which is highly used in the application of Space spare parts, gears, and different machineries Shafts, pinions, bolt and nuts, high speed screw machine parts etc. One of the most types of light and strong metals was selected for this study.

Figure 3.7 Photograph of mild steel rode before machining

3.5 Selection and Characteristics of Cutting Tool Materials

Ceramic coated-carbide tool was used in this study because of their chemical inertness, low thermal conductivity, resistance to high temperature, resistance to flank and crater wear and ceramics are suitable coating materials for tools. The most commonly used ceramic coating is aluminum oxide (Al_2O_3). Table 3.3 shows the composition and properties of ceramic coated carbide cutting tool material. Light cutting of hardened steels and cast irons from 55-65 Rockwell “C” (can cut HSS). Modern ceramics are much tougher than early products and can be used successfully in small lathes in good condition; they can also be used on interrupted cuts. Selection of cutting speed was based on recommended values as shown in Fig.3.6 Cutting speed 80-750 m/min., feed 0.10-0.75mm per rev (4th edition, Kalpakjian, et.al (2003)).

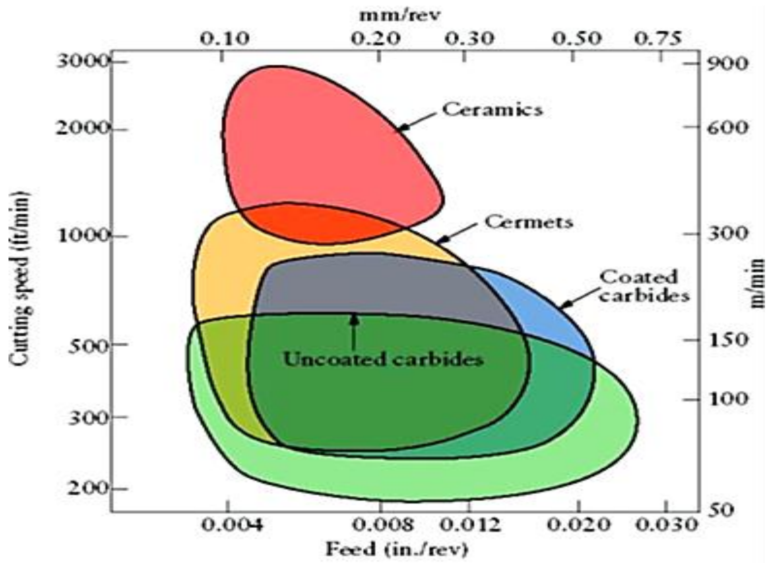

Figure 3.8 Selection of cutting speed

Table 3. 2 The composition and properties of ceramic coated carbide cutting tool.

Cutting Tool	Composition	Hardness (HV)	Thermal conductivity (W/m.k)	Transverse rupture Strength (MPa)	Density (g/cm3)	Young's modulus (GPa)
ceramic coated carbide cutting	Al_2O_3 (97.5 %), ZrO_2 (2.5%)	2100	29	2150	11.6	530

3.6 Tools and Equipment

Conventional engine lathe machine was used for experimental study for turning process of productivity improvement of machining process using double tool. The lathe machine with Harrison M 460 lath machine and power 7KW with spindle speed range of 15 rpm to 2000rpm was used for this study. General view of a typical conventional lathe machine with its main components is shown in the Figure 3.7. Generally, the equipment's and tools used for the study are;

- 3D-Profilometer Optical microscopy
- Lathe machine with model Harrison M 460 lath machine.
- Thermocouple
- Dial Gauge
- Design of Experiment(DOE)

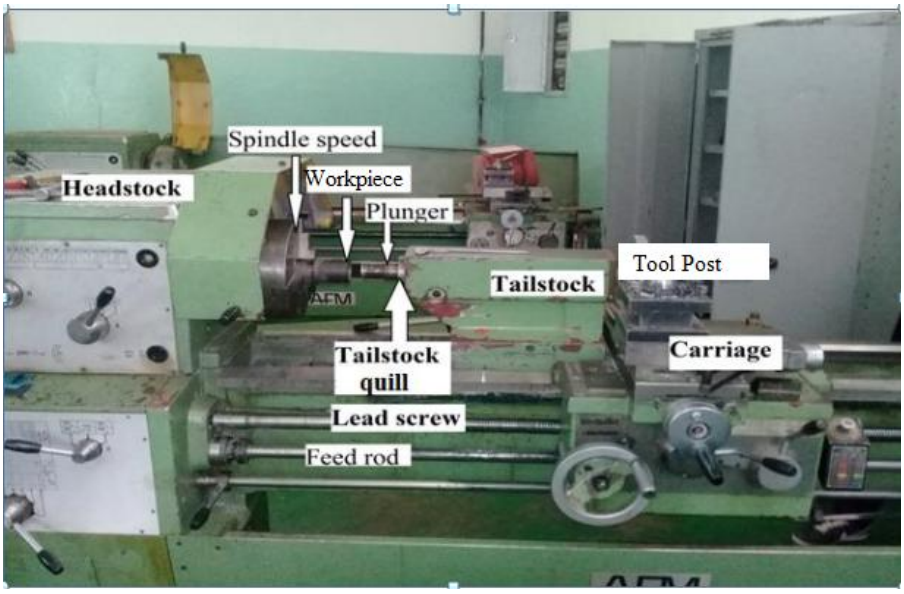

Figure 3.9 General View of a typical Lathe, Showing various Components

3.7 Research Methodology

By using the materials mentioned above through the following method the experimental work would be continued. Under research methodology the way of specimen preparation, design of experiment procedure, selection of orthogonal array, analysis of variance, methods for measuring tool wear, cutting temperature, dimensional error, surface roughness, machining time, material removal rate, and chip formation observation would be explained.

3.7.1 Specimen Preparation for Turning Operation

The workpiece materials used for this study is a common alloy of mild steel which is highly used in the application of Space spare parts, gears, different machineries shafts, pinions, bolt and nuts, high speed screw machine parts etc. Mild Steel rods of 400 mm, 600 mm,700 mm,800 mm,900 mm in length and 35 mm,45 mm,55 mm,65 mm,75 mm in diameter were prepared and it were gone to turning process with 1mm,0.75 mm,0.5mm,0.25 mm depth of cut to remove any irregular parts on the surface for 300 mm of length. Then nine (9) experiments with length of 250 mm for each and (0.25, 0.5), (0.5, 0.75) and (0.75, 1), (1 1.25) mm of depth of cut would be operated with different turning parameters for experimental study with different cutting parameters which is selected by using orthogonal array.

3.7.2 Design of Experiment

In the design of experiment (DOE), Taguchi method is commonly used because it is a problem–solving tool which can improve the performance of the product, process design and system. Design of experiment is a technique of defining and investigating all possible conditions involving multiple factors, parameters and variables in an experiment. To observe the most influential process parameters in the turning process namely cutting speed, feed and depth of cut each at three levels were considered in case of this thesis. The Taguchi design procedure is shown in the Figure 3.8 and the selected process parameters, levels and their values at different levels are given in the Table3.3 and 3.4. Taguchi uses the S/N ratio to measure the quality characteristics deviating from the desired value and it offers three categories of signal to noise ratio as follows;

- Larger the better is suitable for determining the profit, production rate etc.

- Nominal the better is applicable for current.
- Smaller the better is appropriate for surface roughness, tool wear, unit cost etc.

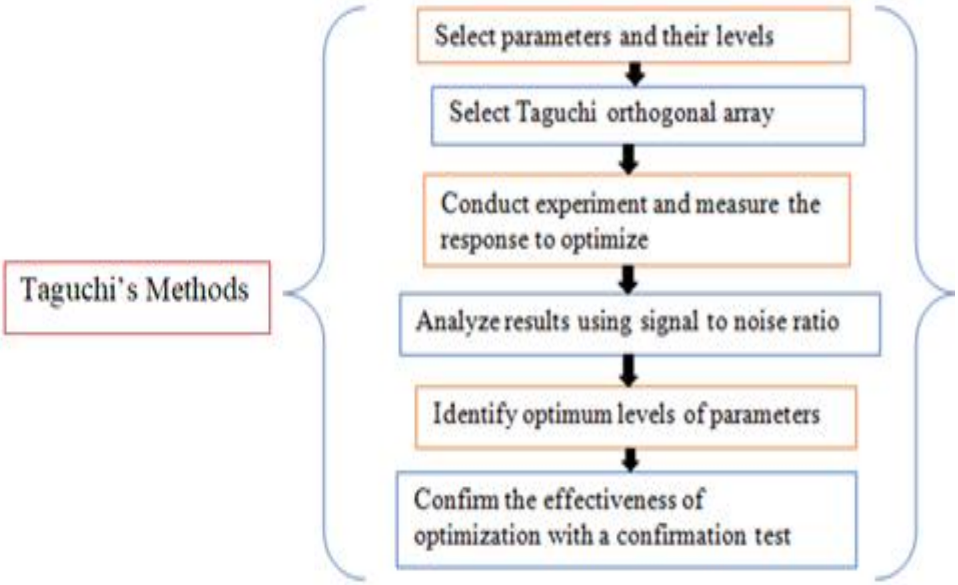

Figure 3.10 Taguchi design procedure.

Cutting parameters were selected depending on the recommended cutting parameters which are given in Table3.3 and 3.4 and the range was taken to get the accurate results, since the maximum difference was at maximum range.

Table 3. 3 List of parameters and their levels for Single Tool Turning

Cutting parameters	Parameters designation	Levels		
		1	2	3
Cutting speed (m/min)	A	170	210	260
Feed (mm/rev)	B	0.24	0.3	0.6
Depth of cut (mm)	C	0.25	0.75	1

Table 3. 4 List of parameters and their levels for Double Tool Turning

Cutting parameters	Parameters designation	Levels		
		1	**2**	**3**
Cutting speed (m/min)	A	170	210	260
Feed (mm/rev)	B	0.24	0.3	0.6
Depth of cut (mm) 1	C	0.25	0.5	0.75
Depth of cut (mm) 2	D	0.5	0.75	1.25

3.7.2.1 Selection of Orthogonal Array and Column Assignment

The turning experiments were carried out on conventional lathe machine by using ceramic coated carbide tools for machining of **Mild Steel Rods** (work pieces) with selected cutting parameters using three levels given in the Table 3.3 and 3.4. According to recommended cutting parameters for Mild Steel. The selection of a particular orthogonal array was based on the number of levels of various factors. Here, to conduct the experiments 3 and 3 factors each at 3 levels were selected. Now the Degree of Freedom (DOF) can be calculated by the formula as given below.

$$DOF=P*(L-1) \quad (3.1)$$

where, DOF= degree of freedom, P = number of factors and L = number of levels

$$DOF=3*(3-1)\approx L_9 \text{ Single tool Turning} \quad (3.2)$$

$$DOF=3*(3-1)\approx L_9 \text{ Double tool Turning} \quad (3.3)$$

However, total number of experiments of the orthogonal array (OA) should be greater than or equal to the total DOF required for the experiment. Thus, L_9 orthogonal array was selected to make the further experiments are shown in the Table 3.5 and 3.6.

This setup allows the testing of all three variables without having to run $27=3^{3.}$ Nine different samples were manufactured with different parameters and at different levels. In the Taguchi method the response variation was studied using signal-to-noise ratio and minimizing by optimizing the responses parameter. The smaller is the better S/N ratio used for these responses.

Table 3. 5 Experimental Layout Using L-9 Orthogonal Array Single Tool Turning

Ex. no	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
01	170	0.24	0.25
02	170	0.30	0.75
03	170	0.60	1.00
04	210	0.24	0.75
05	210	0.30	1.00
06	210	0.60	0.25
07	260	0.24	1.00
08	260	0.30	0.25
09	260	0.60	0.75

Table 3. 6 Experimental Layout Using L-9 Orthogonal Array Double Tool Turning

Ex. no	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm) 1	Depth of cut (mm) 2
01	170	0.24	0.25	0.50
02	170	0.30	0.75	1.00
03	170	0.60	1.00	1.25
04	210	0.24	0.75	1.25
05	210	0.30	1.00	0.50
06	210	0.60	0.25	1.00
07	260	0.24	1.00	1.00
08	260	0.30	0.25	1.25
09	260	0.60	0.75	0.50

$$SN = -10\log\left[\frac{i}{n}\sum_{i=1}^{1}(y_i)^2\right] \qquad (3.4)$$

y is observation, n is total number of observation and y_i is i^{th} response. The S/N ratio was calculated for cutting temperature, dimensional error/deflection, material removal rate, machining time and surface roughness in each of the nine trial conditions to see the effect of each parameter on the response in both single tool turning and double tool turning on the productivity improvement.

3.7.2.2 Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to find which parameters significantly affect the quality characteristic. ANOVA is the statistical technique used to find the influence of all control parameters. In the analysis of variance, the percentage contributions of each control factor were used to measure the corresponding effects on the performance characteristics. The significance level of 5 %, i.e. for 95 % level of confidence was considered in this analysis. ANOVA results indicate whether there is statistically significance in difference or not in output characteristics. ANOVA analysis involves when α values is below 0.05 is significant and above 0.05 is not significant. Percent contribution measures the percentage contribution of each model term relative to the total sum of squares. The percentage contribution is often a rough but effective guide to the relative importance of each model term. From analysis of variance Percentage contribution of each influential parameter was calculated by the following formula:

$$P(\%) = \left(\frac{SSTR}{SST}\right) * 100 \quad (3.5)$$

where, P: Percentage contribution of individual factor,

SSTR: Sum of squares or treatment sum of squares,

MSE: Mean square Error and

SST: Total sum of squares.

3.8 Studying Cutting Temperature

Tool–work thermocouple technique used for this study. All temperature measurement was tested using digital tool-work thermocouple shown in Figure 3.9 the cutting parameters. The thermocouples need some set before making the measurement like (mounting the tip of the thermocouple at the tip of cutting tool, background temperature, time and date). Thermocouples are most commonly used sensor for measuring cutting temperature. The tool–work thermocouple technique is applied to measure the mean temperature over the entire contact area between the tool and the work. The basic configuration of experiment setup is shown in Figure 3.9 This method is based on the fact that an e.m.f. is generated at the interface of two different metals when the temperature of the junction changes. The figure is to measure the tool temperature during a turning operation. The tool–work junction constitutes the hot junction, while the cold junction remains at room temperature, and the e.m.f. is generated depending on the temperature difference between these two junctions. This method measures the mean temperature over the entire contact area between work (chip) and tool (including the flank face). It cannot distinctly measure the temperature difference between work (chip) and rake face from that between work and flank face. However, this measuring technique is used conveniently because it is relatively simple to apply (Childs *et al.* 2000). Thermocouple embedded in cutting tool has also been used to measure the distribution of cutting temperature in it. Temperature distribution at the tool edge can be measured by a fine insulated platinum wire embedded in the tool. The Pt wire constitutes the thermocouple with the chip (Stephenson, D. A. (1993); Childs *et al*. 2000). In this set-up, Junction of tool and workpiece was connected to the thermocouple display. The temperature indicator was used to display the average temperature of tool–work junction.

Figure 3.11 Experimental set-up of tool work thermocouple

3.9 Measurement of Dimensional Error of the Work piece

For this study, the dimensional error is measured by a dial gauge (Make: Mitutoyo) having an accuracy of 1 μm as shown in Figure 3.10. The dial gauge is moved from tailstock to chuck without removing the work piece from the chuck. The work piece is divided into 10 equal divisions for a length of 250 mm. For every division, the work piece was rotated by 60° and the dimensional deviation was measured on 8 equidistant points on the circumference and average value was recorded. The machining experiments were repeated 4 times and a good repeatability was observed.

Figure 3.12 Experimental Set-up of dial gauge

3.10 Tool Wear and Surface Roughness Study

Machinability criteria such as surface roughness, cutting temperature, surface integrity, etc. are often dependent on tool wear and are directly influenced by it. It is under the effect of many parameters such as tool material, coating application, cutting speed, feed, cutting depth and cooling condition, in this section of the study, to evaluate the impact of diverse cooling/lubrication regimes and cutting speed on tool wear. Figure 3.11 shows the set up for the test conducted.

The quality of the surface made using conventional and non-conventional machining is important because a smooth surface reduces the chances of surface damage caused by wear and corrosion. Likewise, quality of a part made by turning operation can affect the performance of the surface for wear and corrosion protection. The surface profiles of all samples were quantitively analyzed in order to determine the statistical standard parameter of average roughness, R_a by using tally surface. The roughness of a surface cannot be easily defined by a single parameter. It's an intrinsic property of the surface and every test condition was repeated at least three times at different new locations on a rod bar surface in order to ensure the repeatability and reproducibility of the result. In this research, after turning process of double tool and Single tool with different cutting parameters, centerline average surface roughness was measured by surface Non-Contact 3D Profilometer as shown in Figure 3.11.

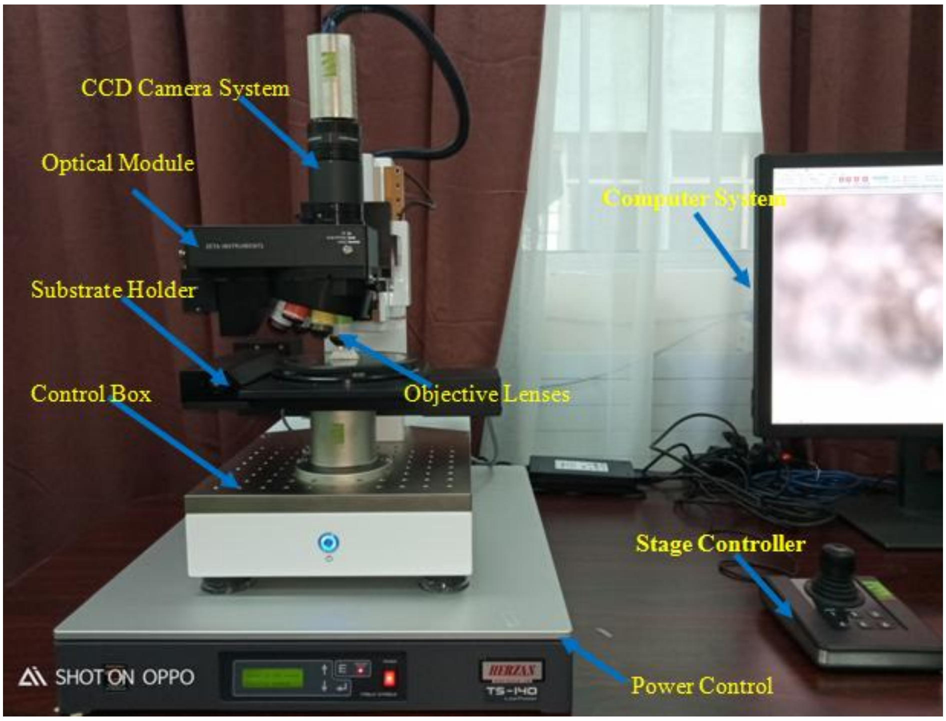

Figure 3.13 Surface Roughness Test Set up

3.11 Chip Formation Observation

Chip formation and effective chip removal are important in those cutting techniques in which the cutting zone is spatially limited, such as drilling, reaming, milling and all turning operations on automatic lathes. The details of chip formation process can be most readily seen using the orthogonal cutting model. In the orthogonal model, chip formation is considered to occur as a two-dimensional process in a plane perpendicular to the cutting edge. During the machining process, the cutting tool penetrates the work material, which deforms first elastically and then plastically. As soon as the shear stress induced by the tool reaches or exceeds the shear strength of the work material in the shear zone, the material begins to flow. Depending on the tool geometry used, the deformed work material forms a chip that flows across the face of the cutting tool. Friction between the contact planes of the tool and the underside of the chip or the new work piece surface creates shear stresses in the secondary shear zones. Generally, four main types of chip can be formed: continuous chips, continuous segmented chips, semi-continuous segmented chips and discontinuous chips.

Continuous chips form when the material is cut flows away continuously from the machining point. The regions of deformed material undergo lamellar sliding but without exceeding the shear strength of the material. If the work material being machined is of sufficient ductility, the chip formed will usually be continuous in form, provided that the cutting process is not impaired by the influence of external vibrations. If the workpiece material is of lower ductility, if it has an inhomogeneous microstructure or if it is subjected to external vibrations, machining will result in the formation of continuous segmented (or serrated) chips. Compared with continuous chips, the upper surface of the chip in this case exhibits a pronounced saw tooth-like structure. Continuous segmented (or serrated) chips can form at high feed rates and at high cutting speeds. Semi-continuous segmented (or serrated) chips, on the other hand, consist of chip sections that were completely separated in the shear zone. This type of chip forms when the degree of deformation in the shear zone exceeds the material's ductility. Discontinuous chips typically form when brittle materials with an inhomogeneous microstructure are machined. It can be observed from these research works that chip features can reveal a lot of information about the machining process. It is also noted that even though a lot of investigation has been done in conventional turning, no work has been reported in double tool turning from the view point of chip Formation. This creates an interest for the author to explore this area.

CHAPTER-4

RESULTS AND DISCUSSION

4.1 Introduction

Experimental study was conducted to evaluate the effect of cutting parameters namely cutting speed, depth of cut, feed and the main performance parameters in a machining process such as; cutting forces, cutting temperature, cutting tool wear, surface roughness, material removal rate, Production rate and dimensional error; The factors determine the production costs, process efficiency and tool life on the Improvement of the production rate during single and double turning machining process. The results for each experiment were discussed under this chapter. Design of experiment was used to identify the optimum cutting parameters and to identify the most influential parameters.

4.2. Analysis of Surface Roughness in Single and Double Tool Turning

4.2.1 Discussion on Experimental and Analytical Results

Turning operation on the specified work piece is done by the double tool and single tool turning processes. Results of the two experiments were obtained, one by using the conventional turning technique (single cutting tool) and other by using the multi- tool turning. The results of the components tested on the surface roughness using 3D-Profilometer Optical Microscope in order to find out the quality of the surface obtained after machining.

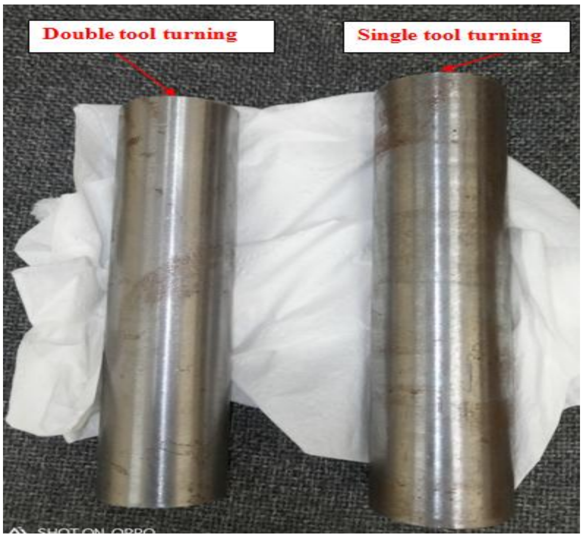

Figure 4.1 Samples of Parts Machined

The Figure of those two turned samples was shown in Figure 4.1. These two components are tested for the surface roughness and the results were analyzed. The results clearly showing that the component turned using the Single Tool turning approach has more Ra value. Average distance between highest peak and lowest valley of sampling was 1.76μm as compared to the one which is obtained after examining the component turned using double tool turning approach which is equal to1.25 μm. So one can conclude that the surface finish obtained in the component turned using multi tool turning is more than the component turned by using conventional turning method. Since in double tool turning two cutting tools were simultaneously engaged with workpiece.

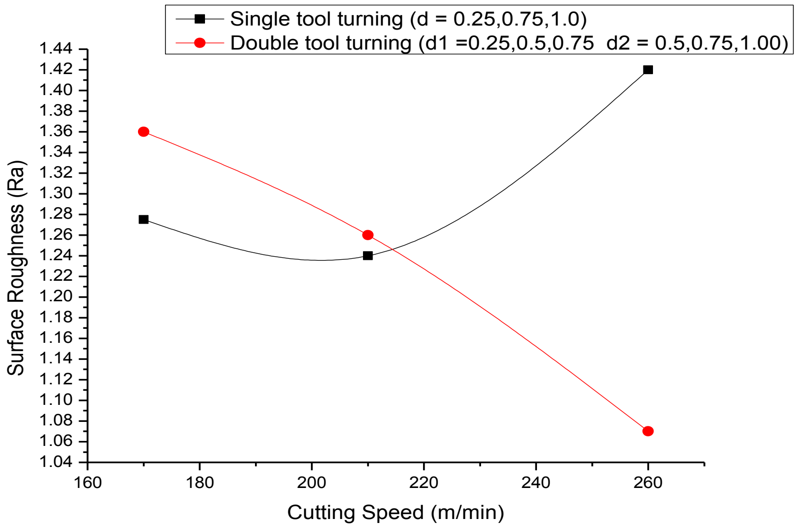

Figure 4.2 Surface Roughness vs. Cutting speed

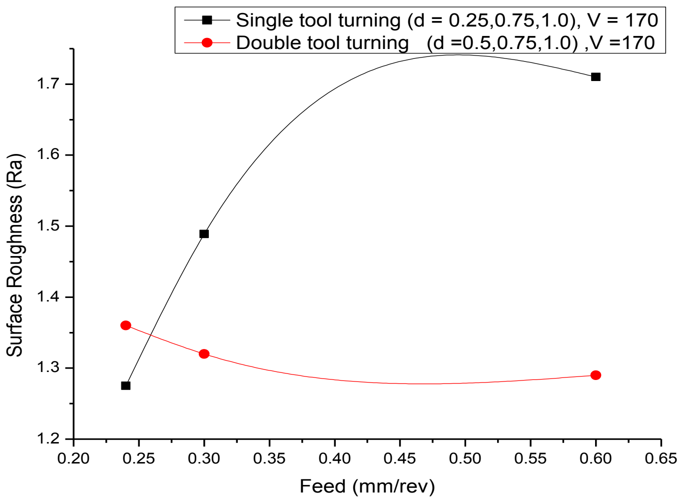

Figure 4.3 Surface Roughness vs. Feed

Figure 4.2 shows that the results of Ra obtained for both single tool and double tool turning. The effect of cutting speed on Ra was shown that from 170m/min to 260m/min Ra was reducing as VC increased. However, double tool turning results better surface finishing when compared with single tool turning. The effect of feed on surface finish evaluated by average surface roughness (Ra) is shown by Figure 4.3. As compared with single tool turning higher surface finish was obtained for double tool turning. The profile of result is measured feed from 0.24 to 0.6mm/rev.

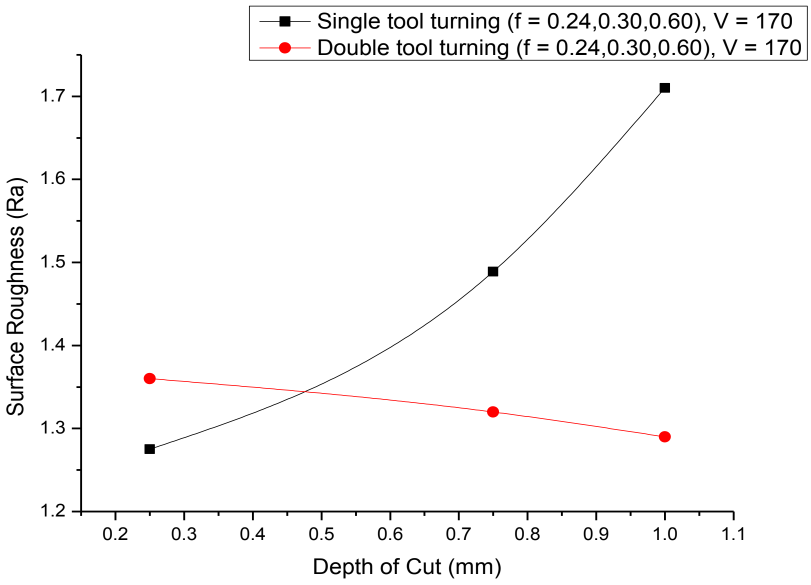

Figure 4.4 Surface Roughness vs. Depth of Cut

As the depth of cut increased Ra was decreased for double tool turning while it was increased exponential for single tool turning. This is because of the advantage of two cutting tools to improve surface finish. The science of double tool turning is economical due to the advantages of better surface finish.

4.2.2 Optimization of Single Tool and Double Tool Turning Process Parameters

The optimization of single tool and double tool turning process parameters on surface roughness during machining of AISI 1018 Steel for given values of machining parameters have been carried out using statistical tool Minitab (version 15.1.0.0, USA). The Taguchi method was used to optimize the results and to determine the optimum level of input process parameters for the best value of surface roughness.

The optimum value of cutting speed, feed and depth of cut was determined to predict the best surface roughness. The adequacy of the model was tested through analysis of variance test (ANOVA).

Table 4.1 and 4.2 shows three factor three level L_9 orthogonal array has been considered in which each factor is considered at three widely spaced levels. A total of three variables have been considered for an experimental design in AISI 1018 Steel available commercially used as the raw material. The conventional lathe machine with modified and necessary attachments has been used as setup to carry out experimentation at various cutting speed, feed and depth of cut.

Table 4.1 Machining parameters and their levels (Single tool turning)

Process Parameters	Level 1	Level 2	Level 3
Cutting Speed	170	210	260
Feed	0.24	0.3	0.6
Depth of Cut	0.25	0.5	0.75

Table 4.2 Machining parameters and their levels (Double tool turning)

Process Parameters	Level 1	Level 2	Level 3
Cutting Speed	170	210	260
Feed	0.24	0.3	0.6
Depth of Cut	0.75	1.0	1.25

The experimental plan and result for surface roughness based on L_9 orthogonal array was shown as Table 4.2.The test of significance of surface roughness was carried out using linear model. The results of the linear model for surface roughness are given in Table 4.3. The value of R and adjusted *R'* are 99.1% and 96.3%.This means that the regression model provides a complete between the dependent and independent variables. The associated *p* value for the model is $p < 0.05$(95% confidence) indicating that the model is considered to be statistically significant. The standard F-value for 95% confidence is 57.4. Hence the model is found to be adequate. It is also seen from table that p values, the main effect of process parameters are much more significant.

Table 4.3 Experimental plan and result for Surface Roughness (Single tool turning)

S. No.	Input Process Parameters			Surface Roughness (Ra)
	Cutting Speed	Feed	Depth of cut	
1	170	0.24	0.25	1.27
2	170	0.30	0.75	1.48
3	170	0.60	1.0	1.71
4	210	0.24	0.75	1.24
5	210	0.30	1.0	2.82
6	210	0.60	0.25	2.56
7	260	0.24	1.0	1.42
8	260	0.30	0.25	1.52
9	260	0.60	0.75	2.05

4.2.3 Predict the Performance of Optimal Levels of S/N Result

For predicting the optimum response approximately, three factors of parameters are selected by low S/N ratio value. **A1B1C2** is the optimum levels of parameters S/N ratio value for surface roughness value. To find out predicted values of the response (surface roughness value) linear regression equation was conducted by eq.4.1.

$$y_{0pt} = m + (mA - m) + (mB - m) + (mC - m) \quad (4.1)$$

y_{0pt}(Predict S/N value for surface roughness in Single Tool Turning)

Table 4. 4 Test for significance of Surface Roughness (Single tool turning)

Cutting Parameters	Coefficient	t – value	P – value
Constant	-5.21606	-8.361	0.014
Cutting Speed(170)	1.14273	1.295	0.032
Cutting Speed(210)	-1.38036	-1.565	0.042
Feed(0.24)	2.05177	2.326	0.027
Feed(0.30)	-0.73337	-0.831	0.047
Depth of Cut(0.75)	-0.08803	-0.100	0.009
Depth of Cut(1.0)	0.64545	0.732	0.05

Table 4.4 and 4.5 shows significant of surface roughness for both double and single tool turning. Figure 4.5 depicts the normal probability of residuals for Surface Roughness. It is observed from the plot that the residual values are distributed normally and in a straight line and hence the model is adequate. The normal probability plot was well distributed.

Table 4.5 Analysis of Variance for SN ratios of Surface Roughness (single tool turning)

Source	DOF	Sum of Squares	Mean Sum of Squares	F-value	P-value
Cutting Speed	2	9.803	4.902	1.40	0.045
Feed	2	19.457	9.729	2.78	0.038
Depth of Cut	2	2.205	1.103	0.31	0.027
Residual Error	2	7.005	3.502		
Total	8	38.470			

Table 4.6 Response table for Signal to Noise Ratios (smaller is better) for Single turning

Level	Cutting Speed	Feed	Depth of Cut
1	4.073	3.164	5.304
2	6.596	5.949	4.571
3	4.978	6.534	5.77
Delta	2.523	3.370	1.203
Rank	2	1	3

As table 4.6 shows the most significant factor that affects surface roughness (Ra) value for single tool turning process is feed, feed affects highly level of surface finish followed by cutting speed. While the depth of cut is the third influential factor.

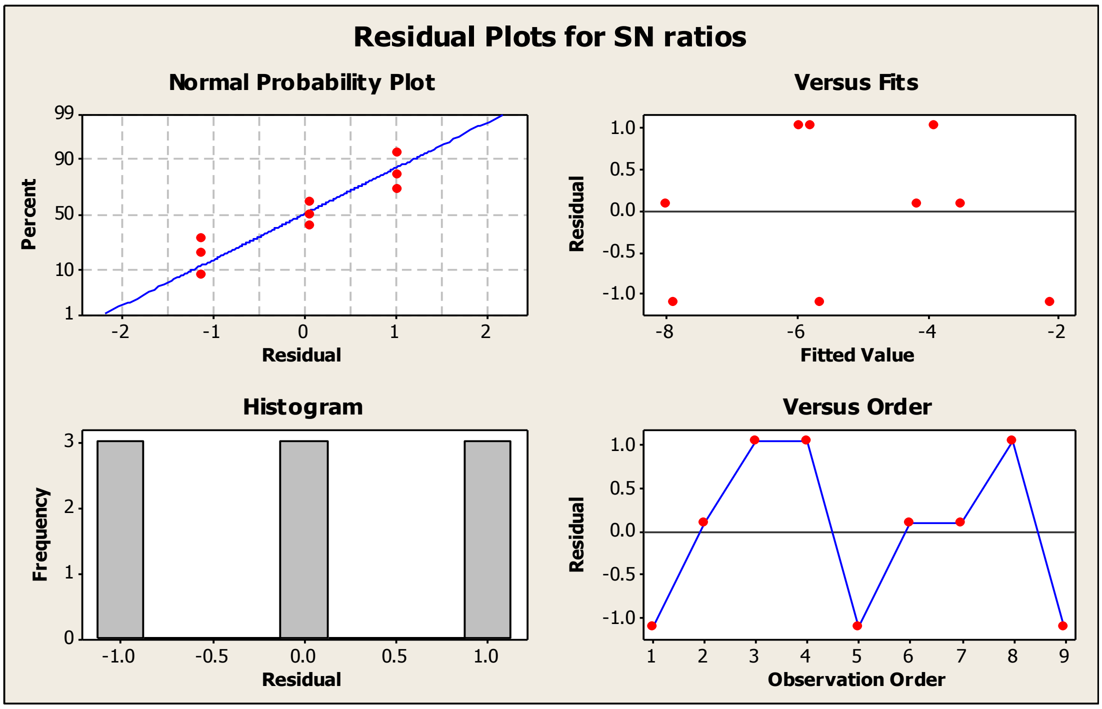

Figure 4.5 Residual plots for mean Surface Roughness (Single tool turning)

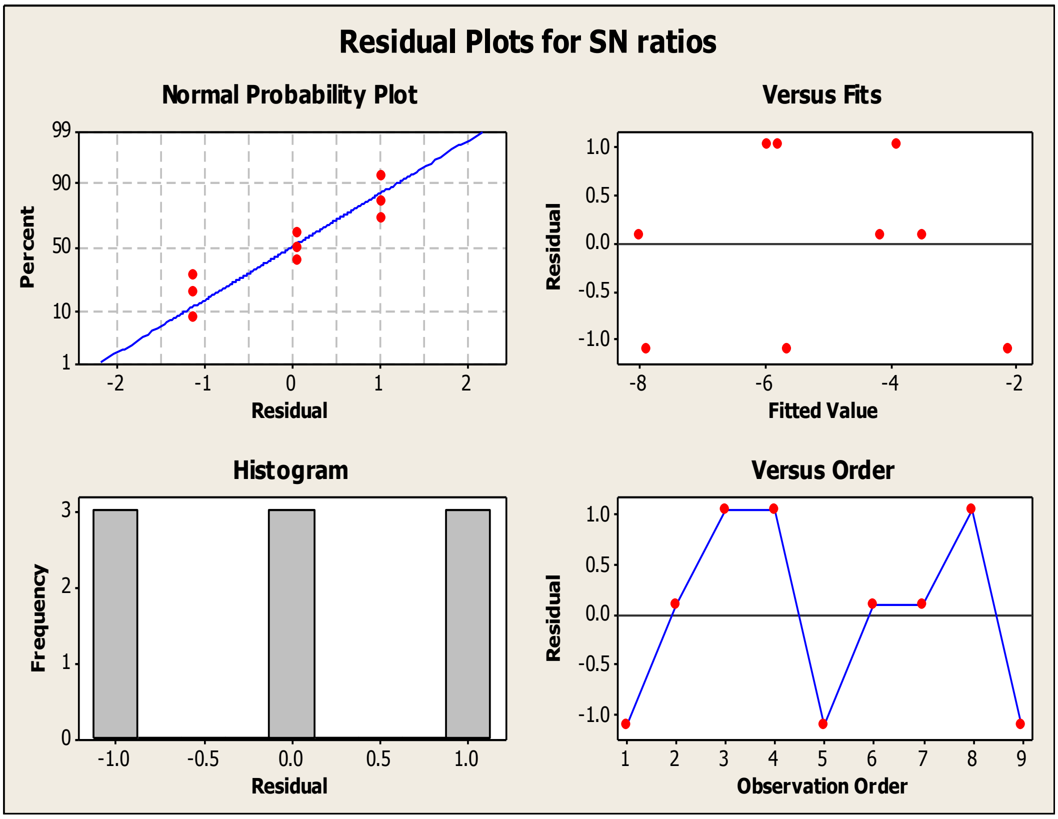

Figure 4.6 Residual plots for SN ratios of Surface Roughness (Single tool turning)

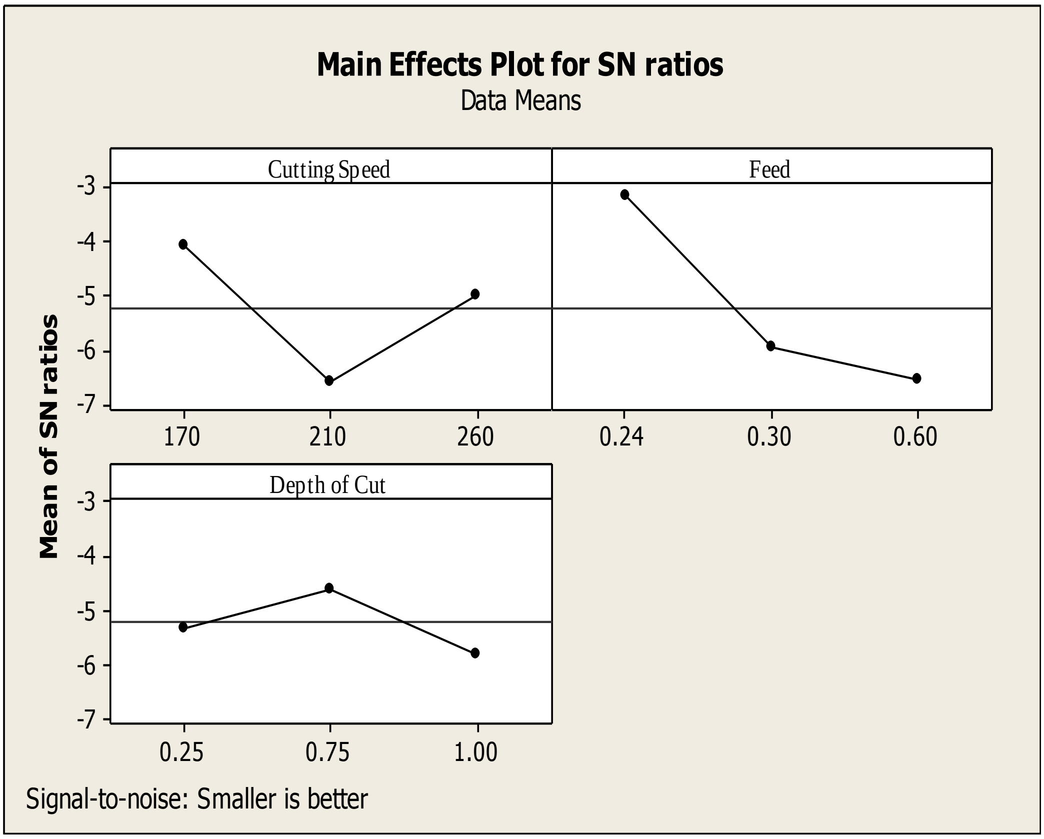

Figure 4.7 Main Effects plots for SN ratios of Surface Roughness (Single tool turning)

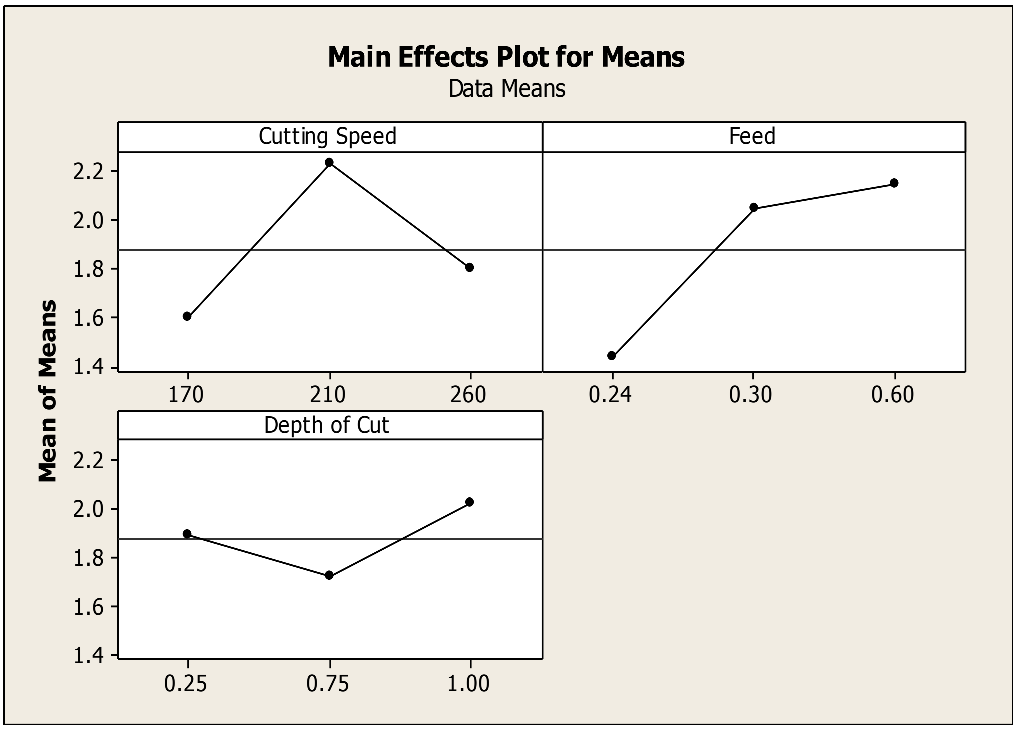

Figure 4.8 Main Effects plots for mean Surface Roughness (Single tool turning)

The test of significance of surface roughness was carried out using linear model. The results of the linear model for surface roughness are given in Table 4.4. The value of R and adjusted R' are 92.5% and 90.3% respectively. This means that regression model provides a complete between the dependent and independent variables.

Table 4.7 Experimental plan and result for Surface Roughness (Double turning)

S. No.	Input Process Parameters			Surface Roughness (Ra)
	Cutting Speed	Feed	Depth of cut	
1	170	0.24	0.75	1.36
2	170	0.3	1.00	1.32
3	170	0.6	1.25	1.29
4	210	0.24	1.00	1.26
5	210	0.3	1.25	1.33
6	210	0.6	0.75	1.25
7	260	0.24	1.25	1.07
8	260	0.3	0.75	1.25
9	260	0.6	1.00	1.38

The associated p value for the model is $p < 0.05$(95% confidence) indicating that the model was considered to be statistically significant. The standard F-value for 95% confidence was 5.36. Hence the model is found to be adequate. It is also seen from the Table 4.8 that p values, the main effect of process parameters were much more significant.

4.2.4 Predicted Value of Performance at Optimal Levels of S/N Results

For predicting the optimum response approximately, three factors of parameters were selected by low S/N ratio value. **A2B1C2** is the optimum levels of parameters S/N ratio value for surface roughness value. To find out predicted values of the response (surface roughness value) linear regression equation 4.2.

$$y_{0pt} = m + (mA - m) + (mB - m) + (mC - m) \quad (4.2)$$

y_{0pt} = (Predict S/N value for surface roughness in Double Tool Turning

Figure 4.9 depicts the normal probability of residuals for Surface Roughness. It is observed from the plot that the residual values are distributed normally and in a straight line and hence the model is adequate. Table 4.8 shows significant of Ra for double tool turning and Table 4.9shows analysis of variance and Table 4.10 shows response table for S/N for smaller is better for double tool. The most significant cutting parameters show cutting speed followed by depth of cut.

Table 4. 8 Test for significance of Surface Roughness (Double tool turning)

Terms	Coefficient	t – value	P – value
Constant	1.27889	30.577	0.001
Cutting Speed(170)	0.04444	0.751	0.031
Cutting Speed(210)	0.00111	0.019	0.006
Feed(0.24)	0.02111	0.357	0.016
Feed(0.30)	-0.04889	-0.827	0.0041
Depth of Cut(0.75)	0.00778	0.131	0.008
Depth of Cut(1.0)	0.04111	0.695	0.0015

Table 4.9 Analysis of Variance for SN ratios of Surface Roughness (Double tool turning)

Source	DOF	Sum of Squares	Mean Sum of Squares	F-value	P-value
Cutting Speed	2	0.6501	0.3250	0.43	0.02
Feed	2	0.5866	0.2933	0.38	0.05
Depth of Cut	2	0.6473	0.3237	0.42	0.05
Residual Error	2	1.5260	0.7630		
Total	8	3.4100			

Table 4.10 Response table for Signal to Noise Ratios (Smaller is better) for Double tool turning

Level	Cutting Speed	Feed	Depth of Cut
1	2.431	2.276	2.182
2	2.141	1.755	2.405
3	1.774	2.316	1.759
Delta	0.657	0.561	0.647
Rank	**1**	**3**	**2**

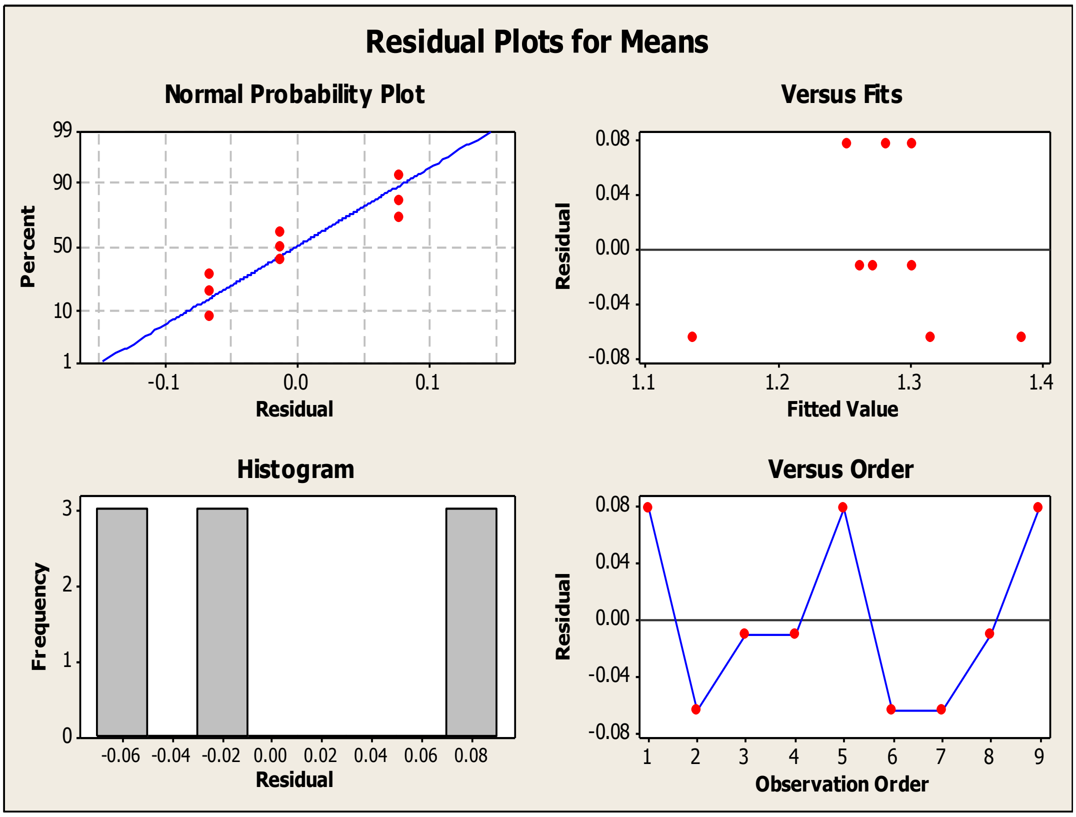

Figure 4.9 Residual plots for Mean Surface Roughness

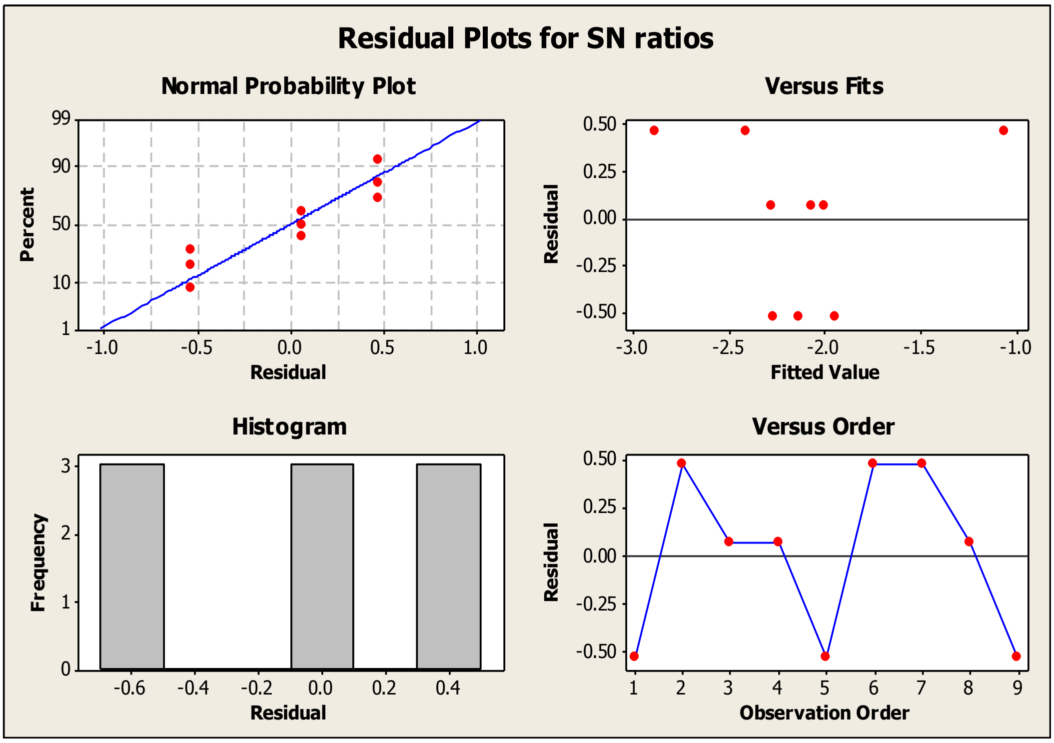

Figure 4. 10 Residual plots for SN ratios of Surface Roughness

The probability plot shown Figure 4.9 show normal distribution and the histogram of residual values well agreed the same trend was obtained from S/N plot shown in Figure 4.10.

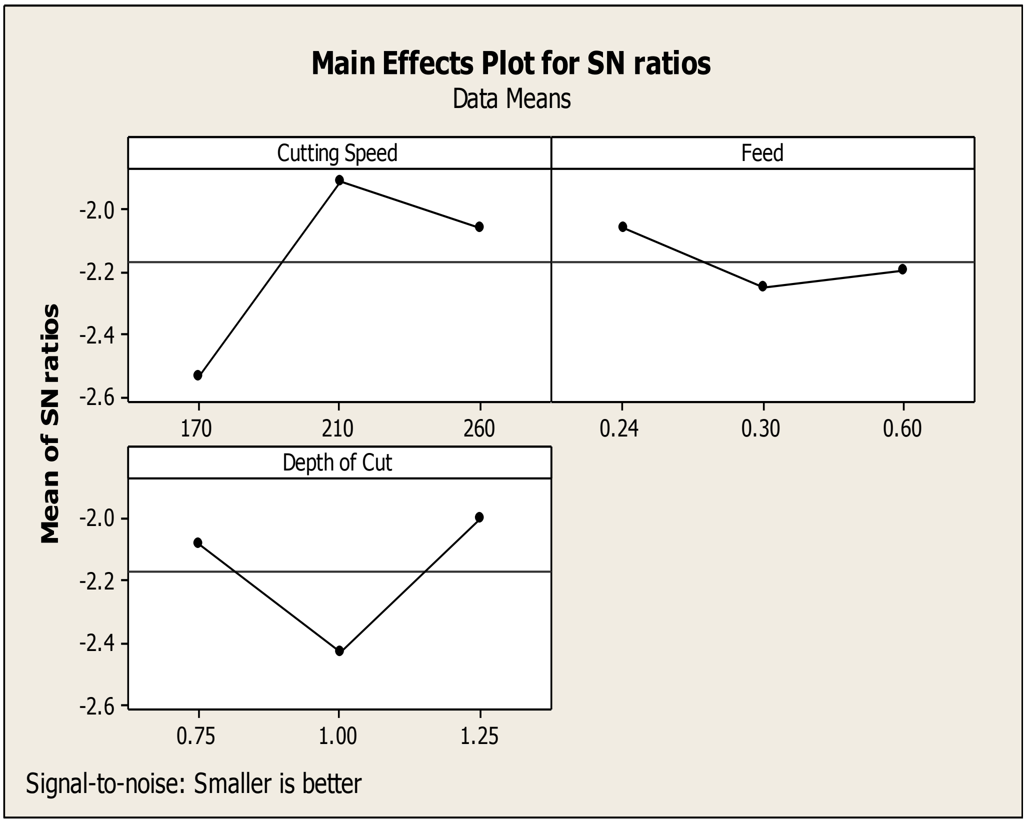

Figure 4.11 Main effects plot for SN ratios of Surface Roughness

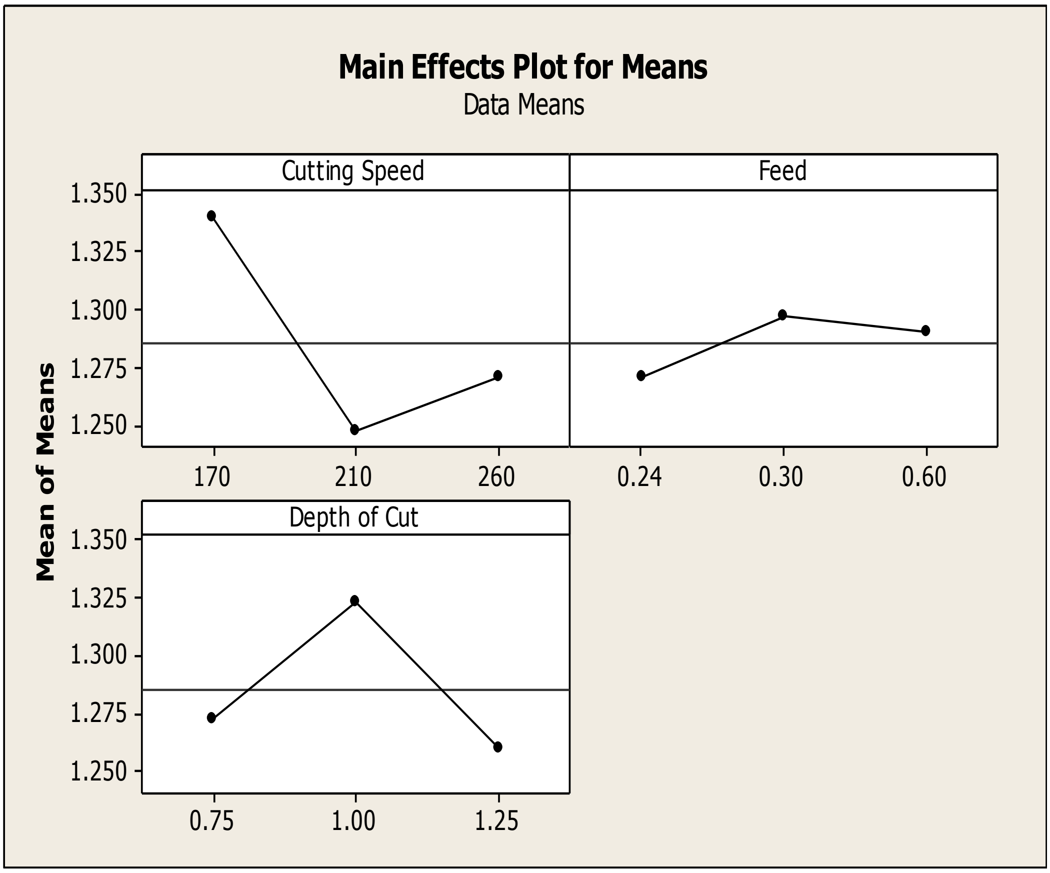

Figure 4.12 Main effects plot for mean Surface Roughness

Figure 4.11 and 4.12 shows the plot of main effects of cutting speed, depth of cut and feed rate parameters on the surface roughness in single tool and double tool turning processes respectively. It was clearly shown that the feed rate and cutting speed significantly affecting the surface roughness (Ra) in case of Single Tool Turning. Feed rate was found more significant factor affecting the (*Ra)* due to the fact that more feed as the depth of cut more. The surface roughness was apparently to a decreased trend with decrease in feed rate due to the fact that the depth of cut shared in between the two tools in case of the double tool turning Process. On the other hand, as the cutting speed increased, the surface roughness decreased.

Therefore, to obtain a low value of surface finish on the machined part, the feed rate should be set at low possible and cutting speed should be set as high as possible. This improved from this study by applying two tools at a time to minimize the depth of cut which cause more feed .Table 4.10 also proves that the cutting speed has more influence on surface roughness than feed rate in double tool turning.

4.3 Evaluation of Dimensional Error

In turning process, the cutting forces acting on the workpiece caused deviation from the desired diameter. This deviation is called diametral error; it is mainly influenced by the radial component of the cutting force. The diametral error was measured by a dial gauge (Make: Mitutoyo) having an accuracy of 1 µm. The dial gauge is moved from tailstock to chuck without removing the workpiece from the chuck. The workpiece was divided into 10 equal divisions for a length of 300 mm. For every division, the work piece was rotated by 60° and the diametral deviation was measured on 8 equidistant points on the circumference and average value was recorded. The machining experiments were repeated four times and a good repeatability was observed.

The diametral deviation from the set diameter increased towards the tailstock end. This behaviour is due to the increased work piece deflection at the tailstock end when compared with the chuck end. The maximum deviation at the tailstock end was 150 µm. The cutting forces generated while turning with a single cutting tool, deflect the workpiece at the mentioned depth of cut than double tool process. When the double cutting tool is engaged, the cutting tool restricts the deflection of the workpiece due to the depth of cut shared by 1st and 2nd cutting tools. Hence the maximum work piece deflection got reduced to 25 µm. This contributes to the improvement of work piece diametral accuracy by 85%. The 1st and 2nd cutting tools act as a follower rest for each other.

It is observed that the dynamic stiffness of the machining system was influenced by the compliance of headstock, tailstock and carriage. Apart from this, the workpiece length, cutting tool, tool post and work holding device such as chuck also affect the dynamic stiffness. The accuracy of holding the workpiece during machining and positioning of cutting tool play a major role in dimensional and shape accuracy. In this Experimental work also, an attempt is made to understand the effect of Cutting speed, feed and depth of cut on dimensional error in double tool and single tool turning. Figures 4.13, 4.14 and 4.15 reveals that the dimensional error affected in Single tool turning while not highly affected due to two single point cutting tools were utilized for turning in double tool turning. Figure 4.13 shows the effect of cutting speed on dimensional error for both single tool and double tool turning processes, dimensional error increased when cutting speed increased. The good advantage of double tool turning was observed reducing the dimensional error. The effect of depth of cut on dimensional error was shown as Figure 4.15.In this case double tool turning reduced the error because of gripping capacity of two cutting tools was effective. Figure 4.14 shows that minimum feed rate dimensional error was less, however, for double tool turning it was much less than single tool turning. For both turning processes there was peak value where error was high and reduced to some values.

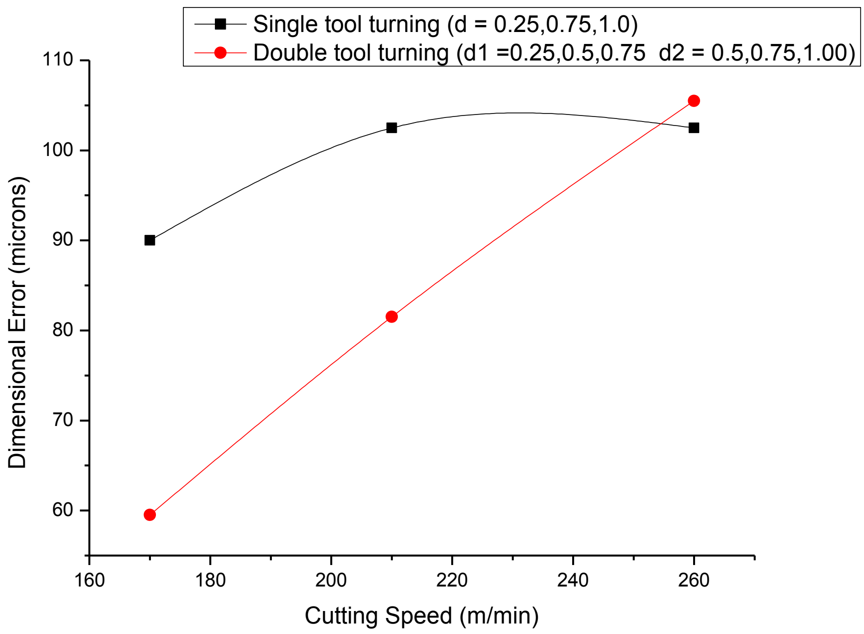

Figure 4.13 Dimensional Error vs. Cutting Speed

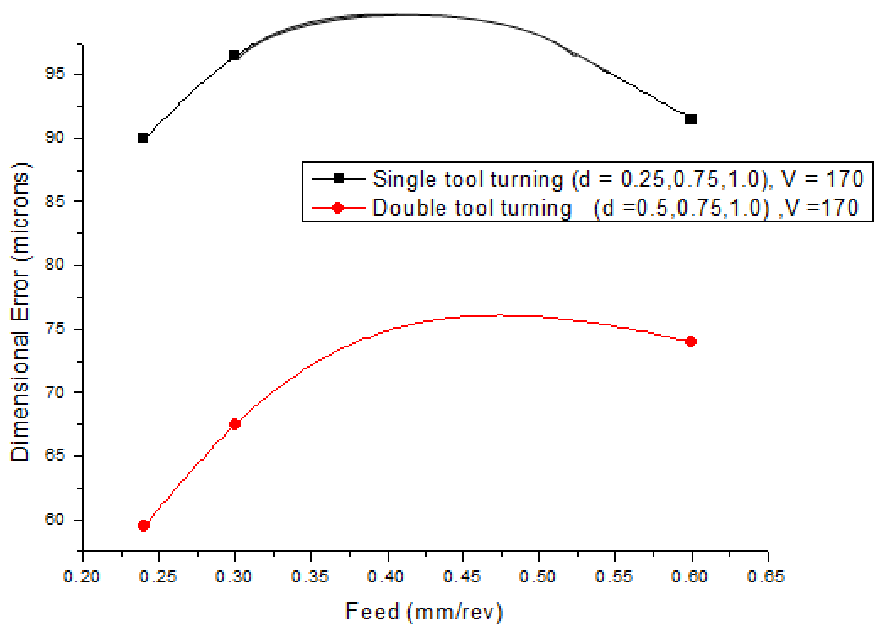

Figure 4.14 Dimensional Error vs. Feed

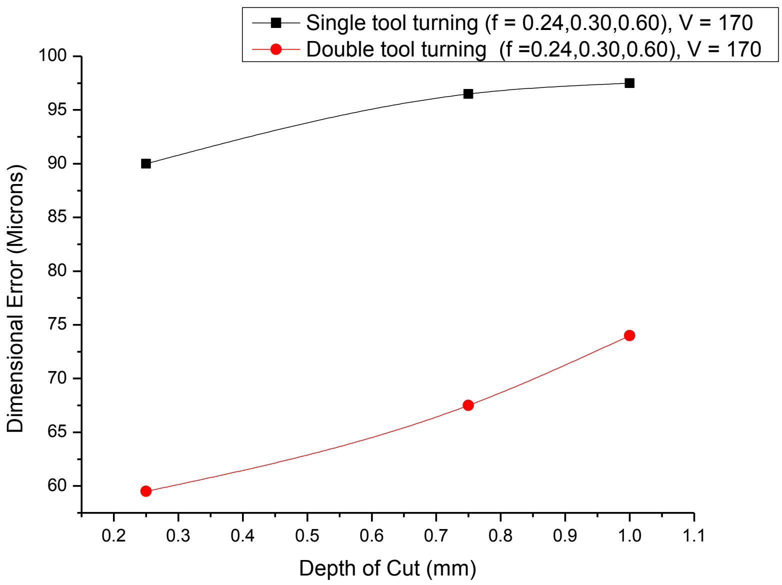

Figure 4.15 Dimensional Error vs. Depth of Cut

4.4 Analysis of Material Removal Rate (MRR)

4.4.1 Discussion on Experimental and Analytical Results

Experimental results of the material removal rate were shows that; at low cost of manufacturing, high quality products, high production rate in short period of time than single point cutting tool in turning process. The Experimental study focused on such a method that will enhance the production rate by minimizing the machining time without affecting the quality of the work finished than the single tool turning method. When using two single point cutting tools together than using single cutting tool than one for the machining of the given component, the material removal volume required for completion of the components or to convert the raw material into the finished component will be reduced to nearly half than that of the Single tool turning. Machining time for turning a given component will be near to half as compared to the Single Tool turning. Double tool turning method played significant role to remove high volume of material rate and can give approximately double production rate than conventional turning method. Based on the equation for material removal rate, the material removal rate of double tool turning processes was calculated as follows with compare of single tool turning process. The equations 4.4 for material removal rate enable the finding of the correct optimal machining modes that can give the maximum material removal rate of the double tool turning process.

Material Remove Rate (MRR) $=\pi D_{avg} df r$ (4.4)

Where $D_{avg} = \frac{D_f + D_o}{2}$, $f_r = fN$

Double tool turning; $MRR = \pi\left(\frac{D_{avg}}{2}\right)(d)fr$

$$MRR = \pi\left(\left(\frac{D_{avg}}{2}\right)mm\right)\left((1.25)mm\right)\left(0.24\ {}^{mm}/_{min}\right)$$

$$= 47.571\ {}^{mm^3}/_{min}$$

Single tool turning; $MRR = \pi\left(\left(\frac{D_{avg}}{2}\right)mm\right)\left((1)mm\right)\left(0.24\ {}^{mm}/_{min}\right)$

$$=38.0568\ {}^{mm^3}/_{min}$$

In case of the multi-tool simultaneous tool turning material remove volume is higher by $9.5142\,{}^{mm^3}/_{min}$ than single tool turning process.

Table 4.11 MRR for single tool turning

Single Tool Data		
Cutting Parameters	MRR	Remarks
Cutting Speed =170mm/min	$38.0568\ {}^{mm^3}/_{min}$	More Passes Required
Depth of cut =1mm		
Feed rate=0.24mm/rev		
Initial Diameter=56mm		
Final Diameter =45mm		

Table 4.12 MRR for Double tool turning

Double Tool Data		
Cutting Parameters	**MRR**	**Remarks**
Cutting Speed =170mm/min	$47.571\ {}^{mm^3}/_{min}$	Less Passes Required
Depth of cut =1.25mm		
Feed rate=0.24mm/rev		
Initial Diameter=56mm		
Final Diameter =45mm		

Table 4.11 and 4.12 shows calculated values of MRR.The Improvement obtained by double tool turning was 20%. From Figure 4.16, 4.17 and 4.18, MRR was highly affected by cutting parameter as cutting speed increased MRR also increased but more MRR was claimed for double tool turning.

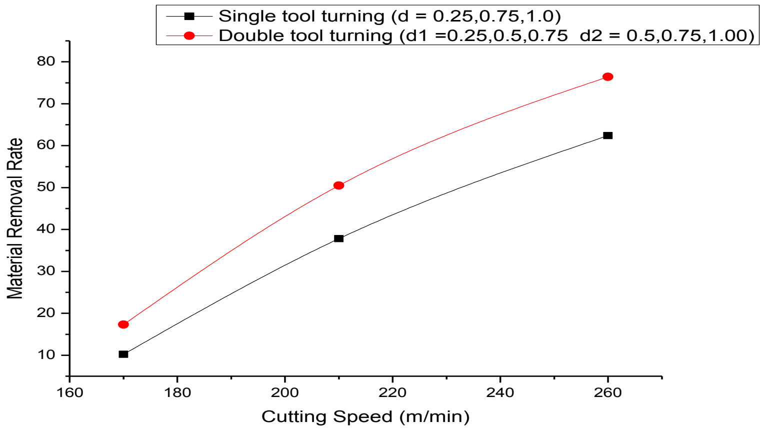

Figure 4.16 Material Removal Rate vs. Cutting Speed

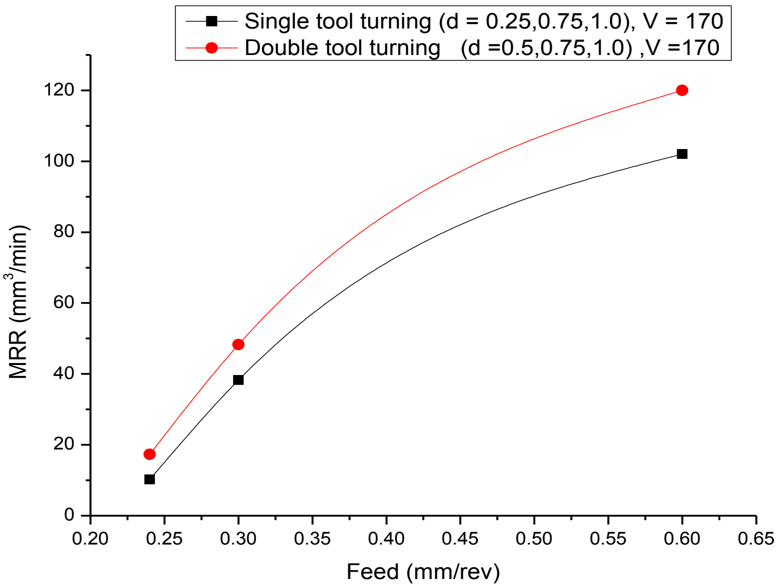

Figure 4.17 Material Removal Rate vs. Feed

The effect of depth of cut on MRR was different from cutting speed and feed from Figure 4.18; it was shown that the graph was exponentially increased; in this case also double tool turning showed best result for removing chips from bulk material. Figures 4.16, 4.17 and 4.18 shows that the materials removal rate in double tool turning mainly increased with the increment of cutting parameters more than single tool turning process. Since removal rate is high in double tool turning without affecting the science of machining the productivity was highly improved.

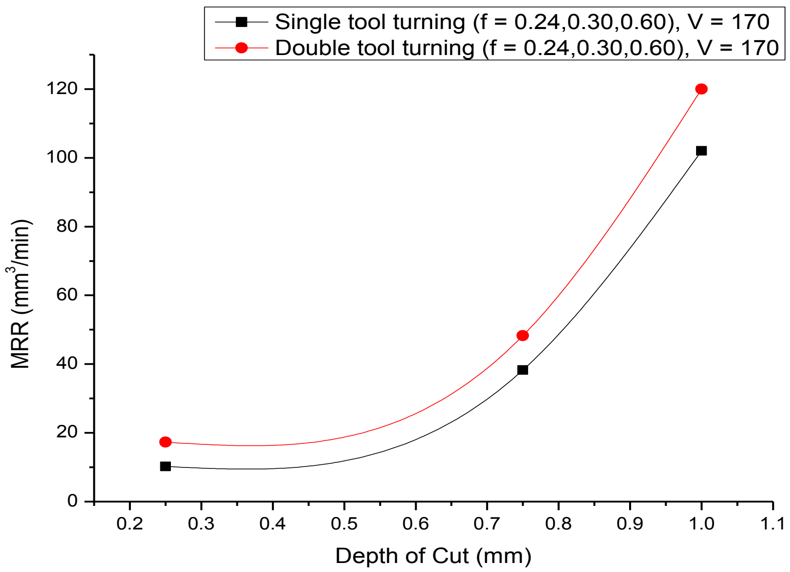

Figure 4.18 Material Removal Rate vs. Depth of Cut

4.4.2 Optimization of Material Removal Rate (MRR)

The optimization of single tool and double tool turning process parameters such as material removal rate (MRR) during machining of work material AISI 1018 steel for given values of machining parameters like cutting speed, feed and depth of cut was carried out using statistical tool Minitab (version 15.1.0.0, USA).The Taguchi method was used to optimize the result and to determine the optimum level of input process parameters for the best value of material removal rate. The optimum value of cutting speed, feed and depth of cut has been determined to predict the best material removal rate. The adequacy of the model was also tested by analysis of variance test (ANOVA).

A three factor three level L_9 orthogonal array was considered in which each factor was considered at three widely spaced levels. A total of three variables were considered for an experimental design for AISI 1018 Steel. Table 4.13 and 4.14 were three levels of process parameters for single and double tool turning, respectively.

Table 4.13 Machining parameters and their levels (Single tool turning)

Process Parameters	Level 1	Level 2	Level 3
Cutting Speed	170	210	260
Feed	0.24	0.3	0.6
Depth of Cut	0.25	0.5	0.75

Table 4.14 Machining parameters and their levels (Double tool turning)

Process Parameters	Level 1	Level 2	Level 3
Cutting Speed	170	210	260
Feed	0.24	0.3	0.6
Depth of Cut	0.75	1.0	1.25

The experimental plan and result for Material Removal Rate based on L_9 orthogonal array was shown as Table 4.15 calculated MRR value for each parameter was obtained.

Table 4.15 Experimental plan and result for MRR (Single tool turning)

S. No.	Input Process Parameters			Material Removal Rate (MRR)
	Cutting Speed	Feed	Depth of cut	
1	170	0.24	0.25	10.2
2	170	0.30	0.75	38.25
3	170	0.60	1.0	102
4	210	0.24	0.75	37.8
5	210	0.30	1.0	63
6	210	0.60	0.25	31.5
7	260	0.24	1.0	62.4
8	260	0.30	0.25	19.5
9	260	0.60	0.75	117

The test of significance of MRR has been carried out using quadratic model. The results of the quadratic model for MRR are given in Table 4.16. The value of R^2 and adjusted R^2 are 99.1% and 96.3%.This means that the regression model provides a complete between the dependent and independent variables. The associated p value for the model is $p < 0.05$(95% confidence) indicating that the model is considered to be statistically significant. The standard F-value for 95% confidence is 57.4. Hence the model was found to be adequate. It was also seen from the Table that p values, the main effect of process parameters were much more significant.

Figure 4.19 and 4.20 depicted the normal probability of residuals for MRR. It was observed from the plot that the residual values are distributed normally and in a straight line and hence the model was adequate. Table 4.18 shows S/N value for analysis confirmed. The most significant machining parameter was depth of cut followed by feed rate.

Table 4.16 Test for significance of MRR (Single tool turning)

Terms	Coefficient	*t* – value	*P* – value
Constant	35.244	96.824	0.000
Cutting Speed (170)	-2.2225	-4.318	0.050
Cutting Speed (210)	-0.1164	-0.226	0.042
Feed (0.24)	-3.0811	-5.985	0.027
Feed (0.30)	-1.0955	-2.128	0.067
Depth of Cut (0.75)	-5.3506	-10.394	0.009
Depth of Cut(1.0)	1.4922	0.5148	0.01

Table 4.17 Analysis of Variance for SN ratios of MRR (single tool turning)

Source	DOF	Sum of Squares	Mean Sum of Squares	F-value	P-value
Cutting Speed	2	31.271	15.636	13.11	0.045
Feed	2	84.411	42.205	35.39	0.027
Depth of Cut	2	137.230	68.615	57.54	0.017
Residual Error	2	2.385	1.192		
Total	8	255.297			

Table 4.18 Response table for Signal to Noise Ratios (Large is better) for Single tool turning

Level	**Cutting Speed**	**Feed**	**Depth of Cut**
1	30.67	29.21	25.31
2	32.50	31.15	34.86
3	34.36	37.35	37.35
Delta	3.69	37.17	12.04
Rank	**3**	**2**	**1**

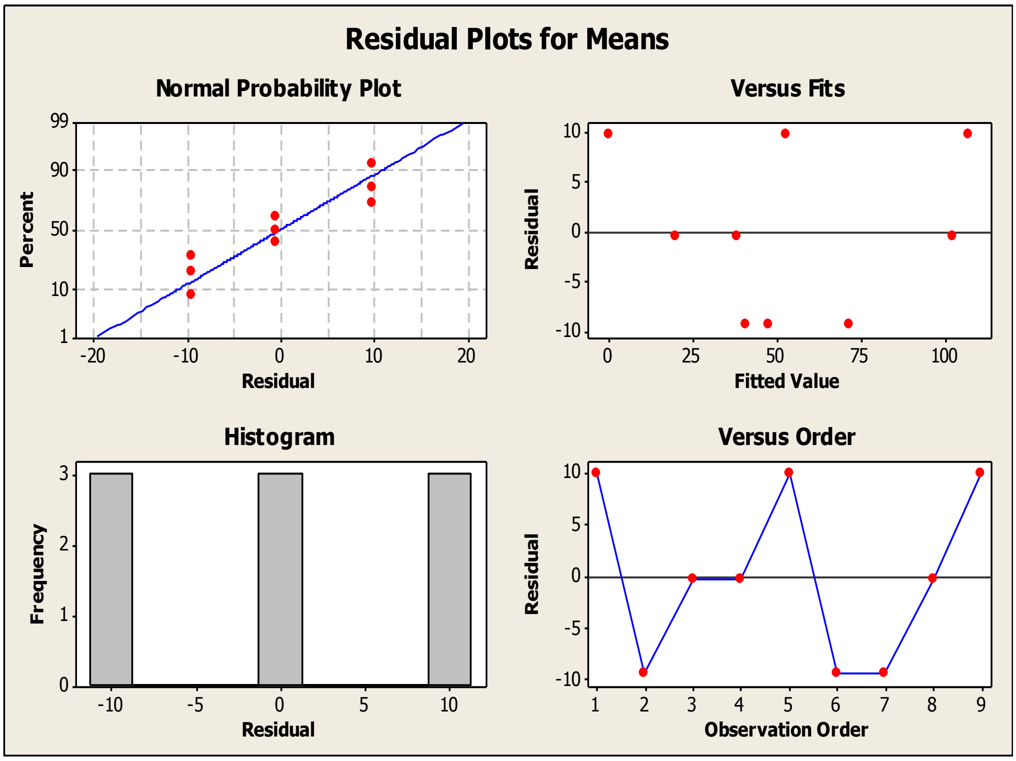

Figure 4.19 Residual plots for mean MRR (Single tool turning)

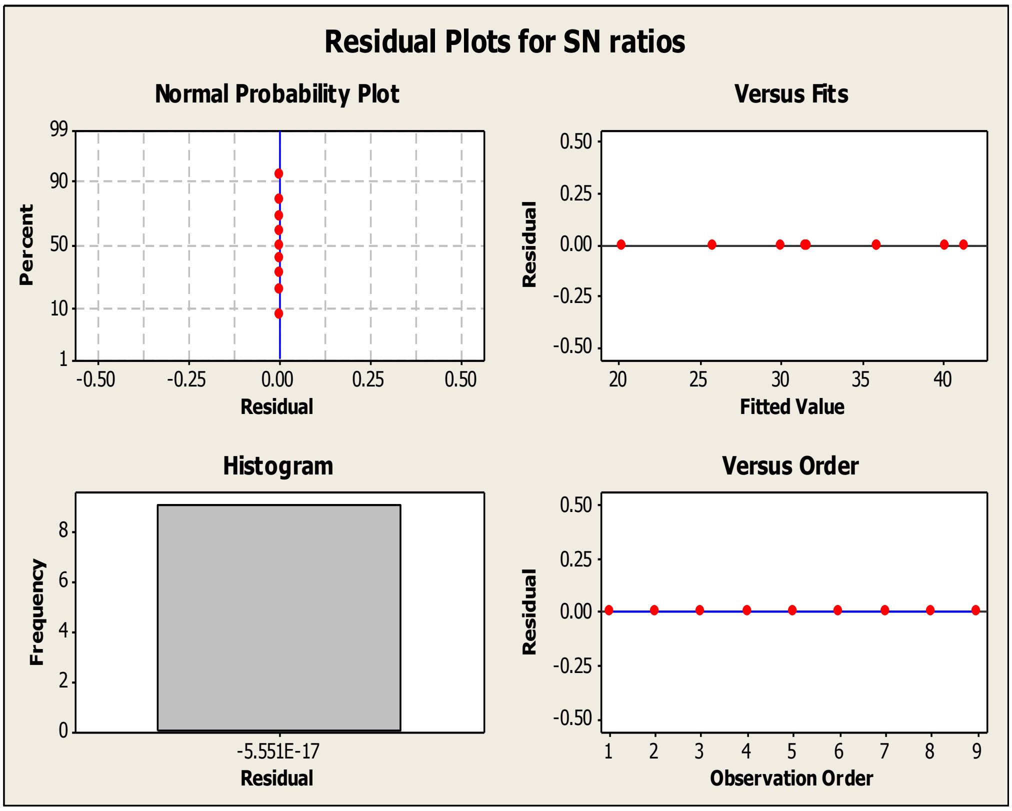

Figure 4.20 Residual plots for SN ratios of MRR (Single tool turning)

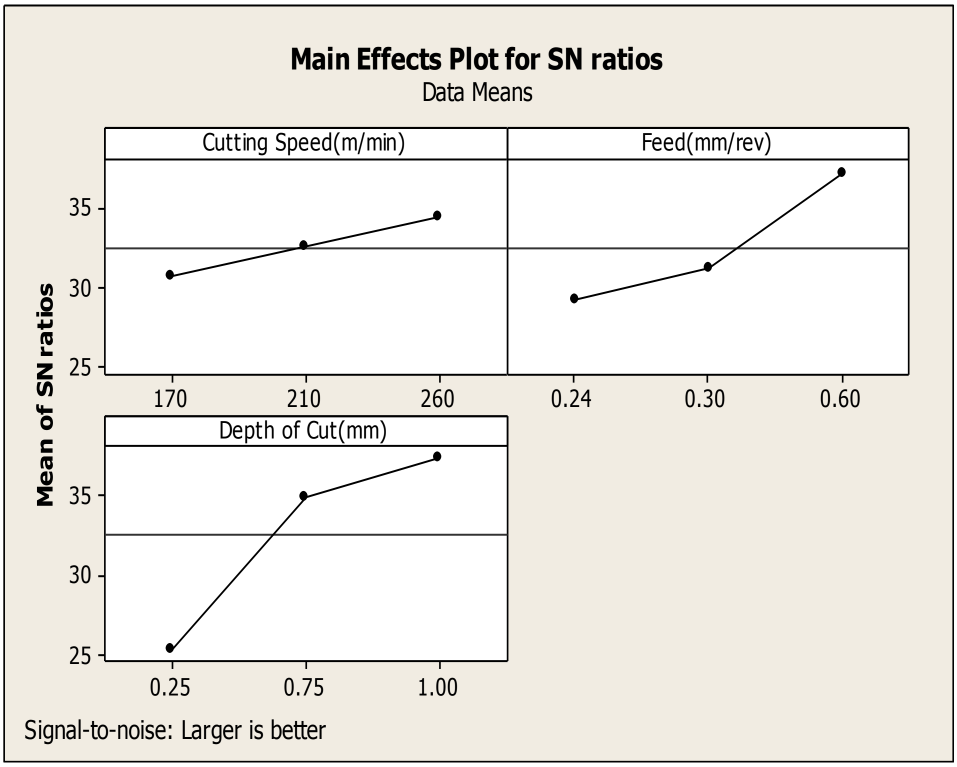

Figure 4.21 Main effects plots for SN ratios of MRR (Single tool turning)

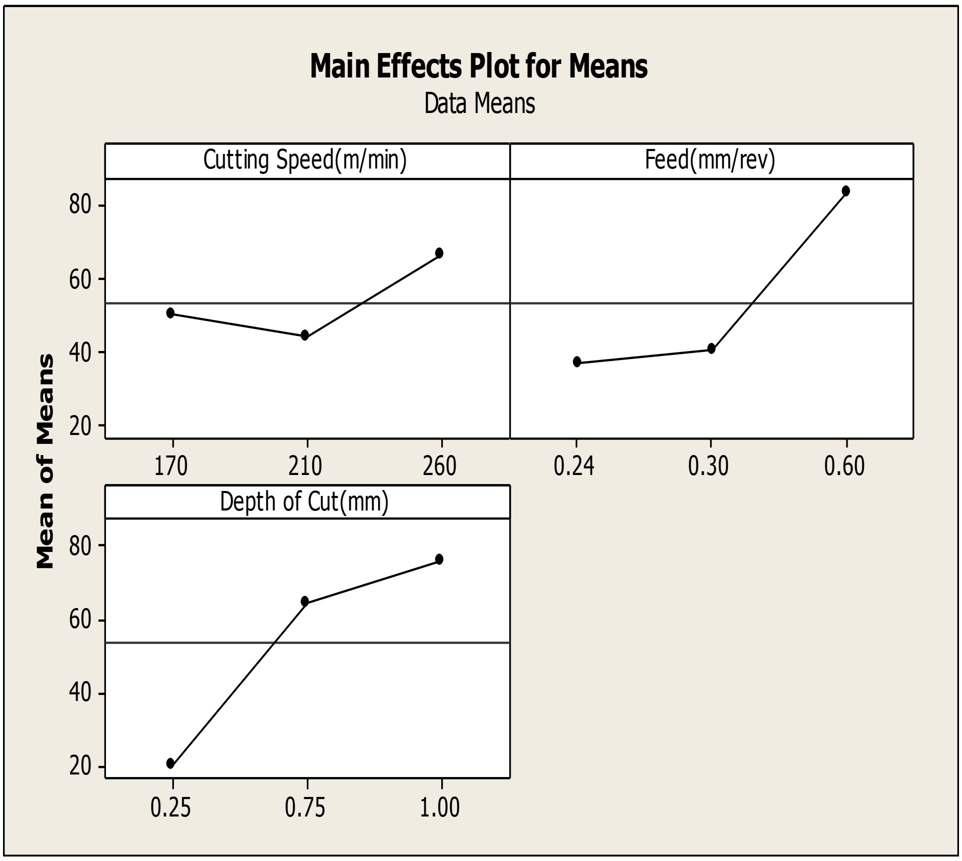

Figure 4.22 Main effects plots for mean MRR (Single tool turning)

Table 4.19 Experimental plan and result for MRR (Double tool turning)

S. No.	Input Process Parameters			Material Removal Rate (MRR)
	Cutting Speed	Feed	Depth of cut	
1	170	0.24	0.5	17.3
2	170	0.3	0.75	43.25
3	170	0.6	1.0	120
4	210	0.24	0.75	50.5
5	210	0.3	1.0	80
6	210	0.6	0.5	46
7	260	0.24	1.0	76.4
8	260	0.3	0.5	38.3
9	260	0.6	0.75	148.3

The test of significance of MRR was carried out using quadratic model. The results of the quadratic model for MRR were given in Table 4.19 the value of R^2 and adjusted R^2 are 92.5% and 90.3%.This means that the regression model provides a complete between the dependent and independent variables. The associated p value for the model is $p < 0.05$(95% confidence) indicating that the model is considered to be statistically significant. The standard F-value for 95% confidence is 5.36. Hence the model is found to be adequate.

Table 4.20 Test for significance of MRR (Double tool turning)

Terms	**Coefficient**	***t* – value**	***P* – value**
Constant	68.894	8.946	0.012
Cutting Speed (170)	-8.711	-0.800	0.008
Cutting Speed (210)	-10.061	-0.924	0.005
Feed (0.24)	-20.828	-1.912	0.016
Feed (0.30)	-15.044	-1.381	0.001
Depth of Cut (0.75)	-35.028	-3.216	0.005
Depth of Cut (1.0)	11.789	1.082	0.002

It is also seen from table that p values, the main effect of process parameters are much more significant. Figure 4.23 depicted the normal probability of residuals for MRR. It was observed from the plot that the residual values are distributed normally and in a straight line and hence the model is adequate. The optimized machining parameters are well proved. From Table 4.22 depth of cut was more significant parameter.

Table 4.21 Analysis of Variance for SN ratios of MRR (Double tool turning)

Source	DOF	Sum of Squares	Mean Sum of Squares	F-value	P-value
Cutting Speed	2	1589	794.3	1.49	0.02
Feed	2	5841	2920.4	5.47	0.05
Depth of Cut	2	5718	2859.0	5.36	0.05
Residual Error	2	1068	533.8		
Total	8	14215			

Table 4.22 Response table for Signal to Noise Ratios for Double tool turning

Level	Cutting Speed	Feed	Depth of Cut
1	33.02	32.16	29.89
2	35.13	34.15	36.74
3	37.58	39.42	39.10
Delta	4.56	7.26	9.21
Rank	3	2	1

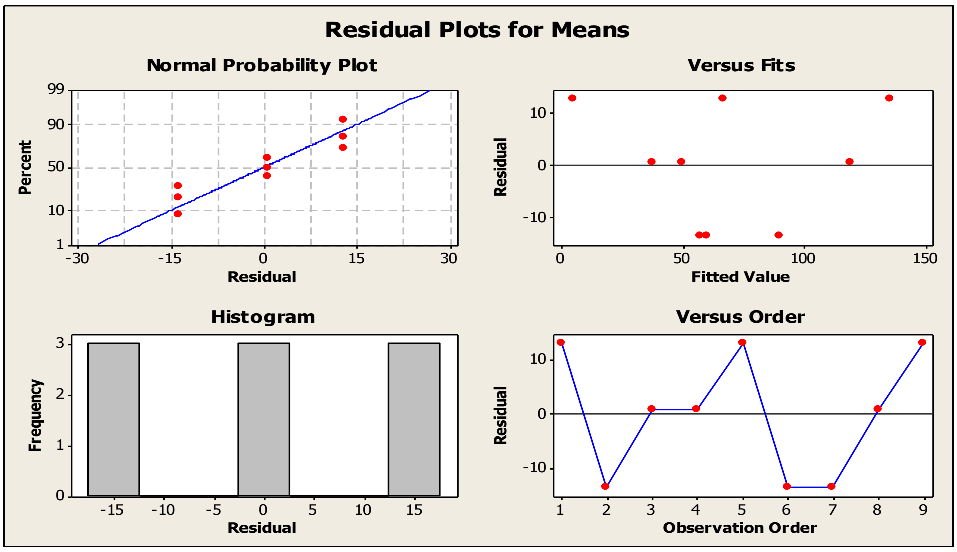

Figure 4.23 Residual plots for Mean MRR

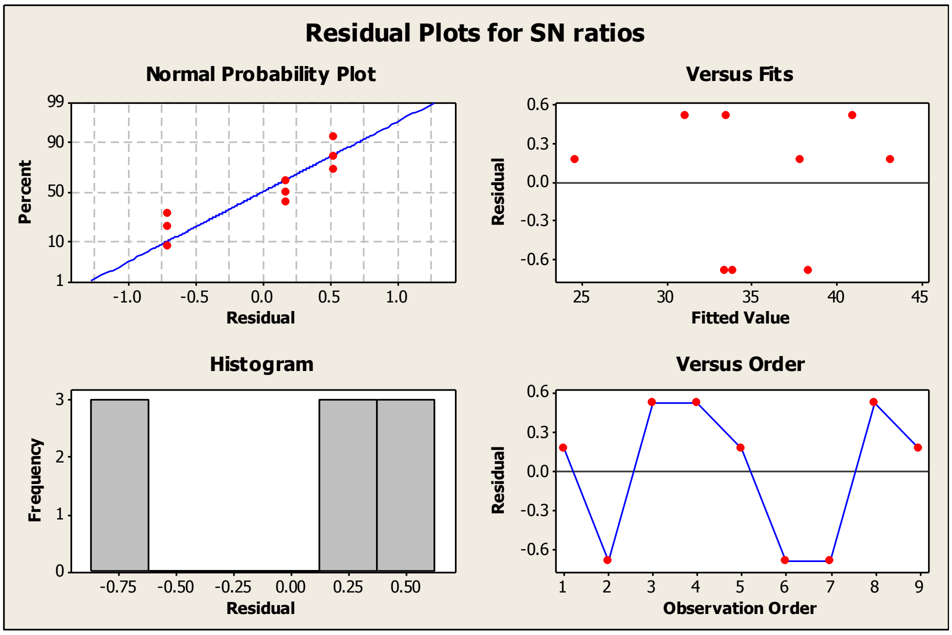

Figure 4.24 Residual plots for SN ratios of MRR

Figures 4.23 and 4.24 shows residual plot of MRR and Main effect plot for S/N ratios

Figure 4.24 and 4.25 showed the main effects of cutting speed, depth of cut and feed rate parameters on Material Removal Rate (MRR). The Depth of Cut followed feed rate is more significant parameters than cutting speed in controlling the MRR. As the Depth of cut increase, MRR also increase, this is mainly due to more volume of chips generated during machining. The optimum of MRR is obtained at feed rate of 0.6 mm/rev, depth of cut of 1.25mm and cutting speed of 260 m/min in double tool turning while at feed rate of 0.6 mm/rev, depth of cut of 1.0 mm and cutting speed of 260 m/min in single tool turning.

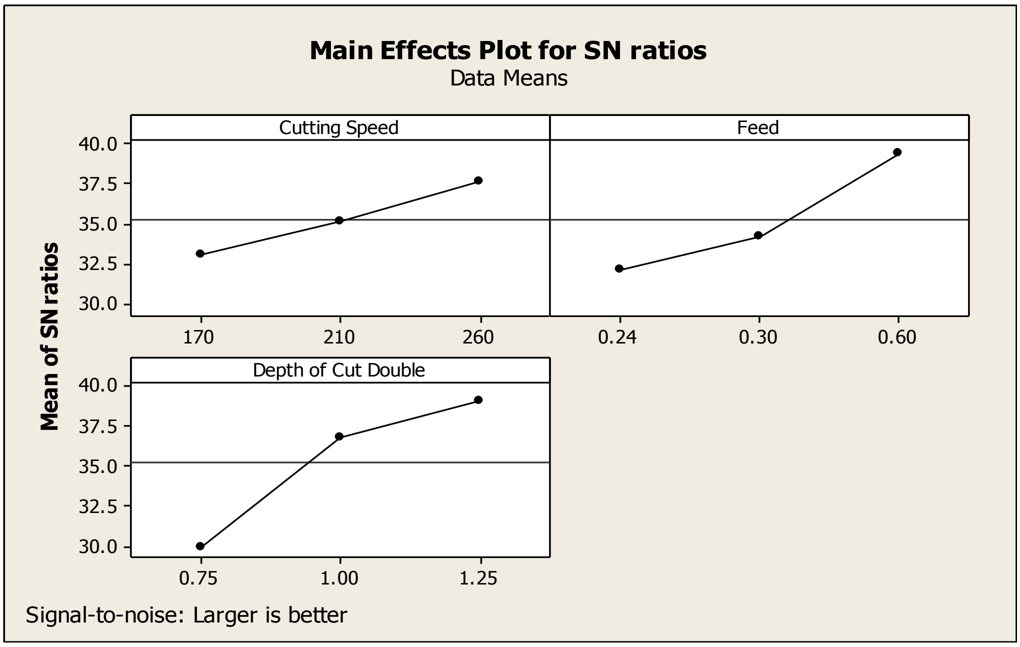

Figure 4.25 Main effects plot for SN ratios of MRR

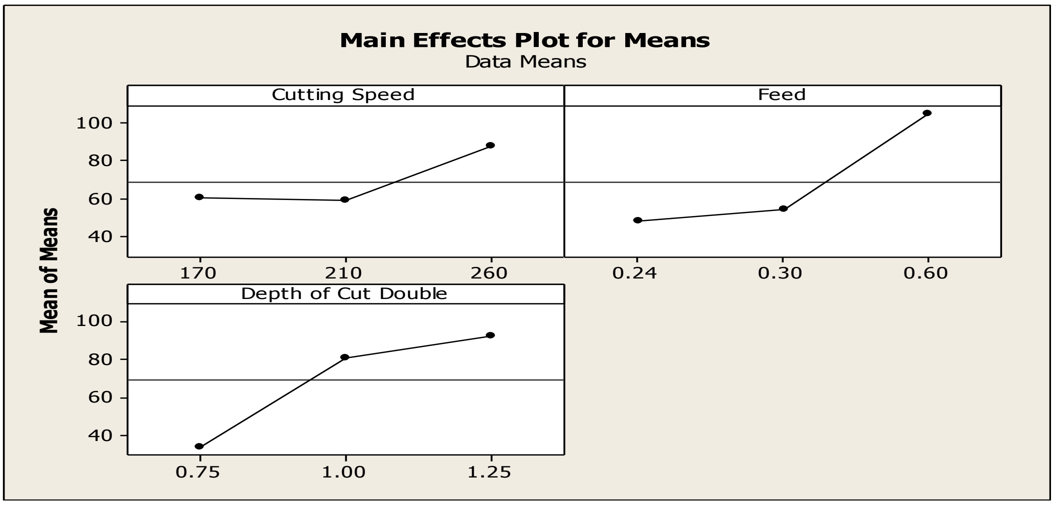

Figure 4.26 Main effects plot for mean MRR

This phenomenon's is similarly obtained by Jaharah *et al*. (2009a) where the depth of cut is significantly affecting the MRR p*roduced*, followed by the cutting speed and feed rate. Besides, Ghani *et al*. (2002) investigated that surface finish of the work part was not influenced by the tool wear; however, it was influenced by increase of cutting speed, feed rate or depth of cut.

4.5 Analysis of Productivity Rate

The Experimental results of Double tool turning conducted show that increased in the productivity rate of machine tools has led to an intensification of the machining process, which reflects the reliability parameters of the machine tool components than single cutting tool turning process. Hence, intensification in machining processes of double tool machine leads to an increase in the productivity rate by reduce the number of passes required and reduces the machining time than single tool process. These circumstances illustrate that machine tools should have optimal machining parameters capable of providing maximum productivity rate. Usubamatov R, *et.al* (2013) developed the analytical expressions of the productivity rate, which include all parameters of the machining processes are very important in manufacturing areas because they allow for the prediction of machinery output with a relatively high accuracy. The results from the study analysis; a machining process in both cases are characterized by the following parameters: cutting speed, feed rate, and depth of the cut. Feed rate and depth of the cut cannot be changed in large-scale operations due to limitations in the quality of the surface and the accuracy of the machining process. However, the cutting speed can be changed over quite a sizable range. With the increase in cutting speed comes a reduction in the surface roughness of a machined part, increased accuracy in machining, and an increase in the productivity rate of the machining process. Also, it is known that intensification of the machining process reflects the more intensive wear process of machine tool units due to an increase in the depth of cut and primary motion speeds. As a result, machine tools must go through more maintenance and repair processes that ultimately lead to a reduction in their output and economic efficiency in case of single cutting tool Turning when less cases in double tool turning.

4.6 Machining Time

Figures 4.27, 4.28 and 4.29 shows effect of machining parameters on machining time. Initially it's observed from the graph that the machining time increased with increase in depth of cut at constant feed given to the tool in single tool as well as in double tool turning operation. This is due to more resistance offered by the material to the cutting tool. Since the process is not stabilized initially, therefore, the tool consumes more time to cut a given amount of material. When the process reaches the equilibrium stage then the tool consumes less time as compared to the initial stage time. From this study one can conclude that the machining time consumed in double tool turning at any given cutting speed and Depth of cut is less than the time consumed in Single tool turning operation. It's because the equilibrium stage is achieved very soon with onset of the process. The optimum values reached, and then machining time decreased as cutting speed increased. For machining same length and diameter of workpiece, double tool turning had reduced machining time as shown from Figure 4.27.As feed rate increased machining time also increased.

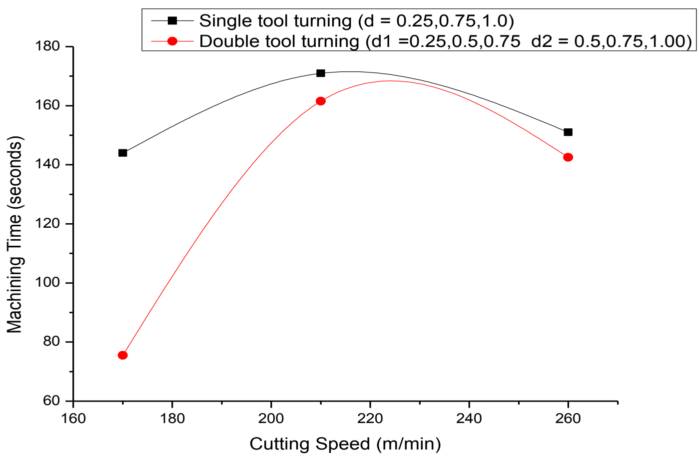

Figure 4.27 Machining Time vs. Cutting Speed

The major aim at machining industries generally focused to

- Reduce total manufacturing time, T
- Increase in MRR, i.e., productivity
- Reduction in machining cost without sacrificing product quality
- Increase in profit or profit rate, i.e., profitability.

All those objectives were commonly and substantially improved by this experimental study of double tool turning process. Hence, number of passes used is generally one or maximum two; one for roughing and one for finishing while numbers of passes observed in Single tool turning process which consumes more time. Figures 4.27 to 4.29 reveals that the machining time much more in single tool turning when the cutting Parameters were increased and the reverse in double Tool turning process. This confirmed that double tool turning can improve productivity.

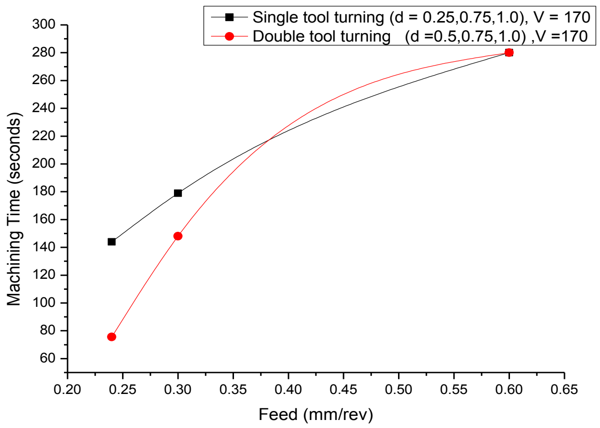

Figure 4.28 Machining Time vs. Feed

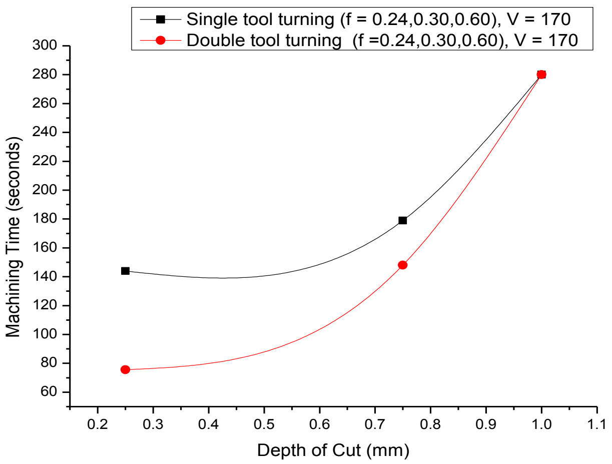

Figure 4.29 Machining Time vs. Depth of Cut

4.7 Analysis of Temperature

The experiment was conducted for both double tool and single tool turning to analysis the temperature differences between them. The test was at contact area between tool-work junction, which produces an electromotive force (e.m.f) while the tool or the workpiece material themselves from the cold junctions. The tool-work (dynamic) thermocouple technique was used. Stephenson, D. A. (1993) used this technique for measuring the temperature in cutting tests on grey cast iron and aluminium with WC tools. The tool-work (dynamic) thermocouple technique was used to measure the net average surface temperature of the workpiece during double tool turning. Two different regions were considered, one region is the 1st cutting tool work interface (*T1st)* another is the 2nd cutting tool work interface (*T2nd)*. The temperatures of these two regions were measured with respect to time.

It is to be noted that this temperature is not an actual temperature of the tool-work interface. It was only the average temperature of the workpiece near tool-work interface. This temperature can provide the relative amount of heat generated by 1st and the 2nd cutting tools. The mean cutting temperature gradually increased in the beginning and reached saturation for both the 1st and the 2nd cutting tools. It was to be noted that the cutting speed and feed of both cutting tools are same, since both are mounted on the same carriage. Figures 4.30 to 4.31 showed that average temperature at the interface of workpiece near the 1st and the 2nd cutting tools.

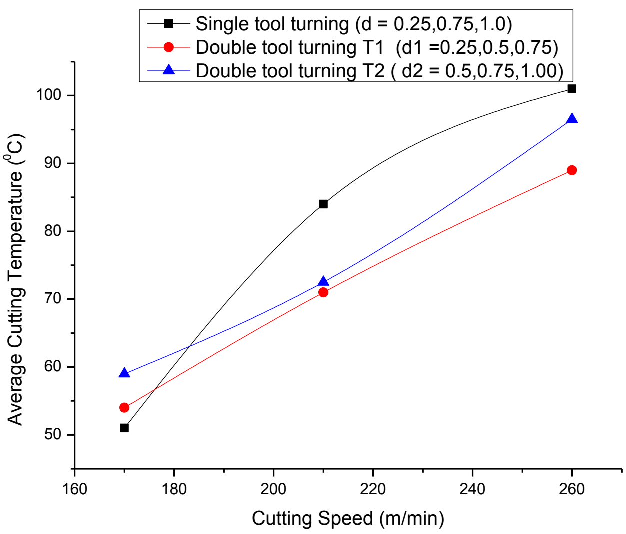

Figure 4.30 Cutting Temperature vs. Cutting Speed

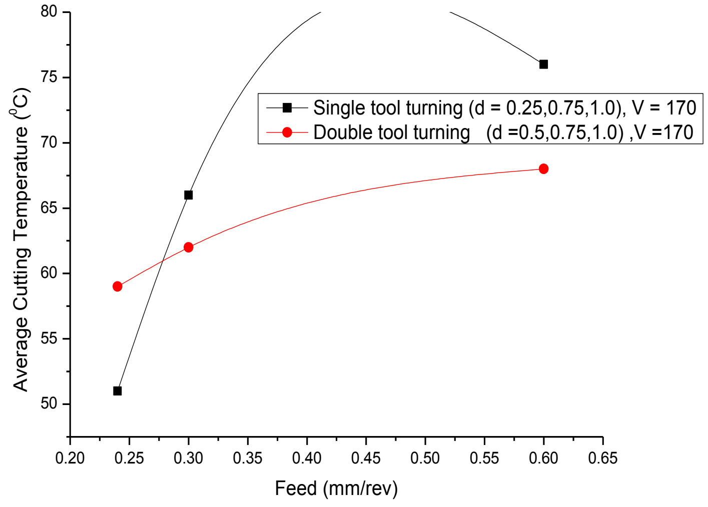

Figure 4.31 Cutting Temperature vs. Feed

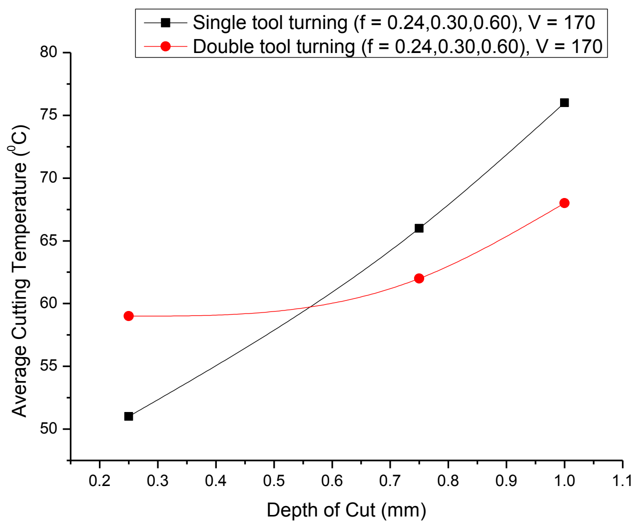

Figure 4.32 Cutting Temperatures vs. Depth of Cut

The region near the 2nd cutting tool exhibited higher temperature when compared with the region near the 1st cutting tool. This behaviour was due to heat generated by the 1st cutting tool during machining shared to double tool. The results confirmed that workpiece temperature is higher when the 2nd cutting tool removed the material when compared with the 1st cutting tool. During single tool process; the temperature measured show that cutting tool exhibited higher temperature due to high depth of cut which causes higher feed rate. The level of surface finish obtained in single tool turning was less than double tool turning. As cutting speed increased temperature was linearly increased but less for double tool process. Therefore it is maintained and confirms the relation of V_C was directly proportional to T^m.

In the double tool turning, the effect of cutting speed and depth of cut on the cutting and feed were similar to the conventional turning process. By utilizing two cutting tools, the rate of material removal and hence productivity can be increased by 20%. The relative position of one cutting tool with respect to the other cutting tool is an additional parameter in addition to the conventional turning parameters. Hence, an attempt was made to understand the effect of distance between 1st and the 2nd cutting tool on cutting temperature. With the increased in cutting speed, workpiece exhibited an increased in temperature between and cutting tool. While less temperature between tool and machined surface.

Figure 4.30 reveals that the workpiece temperature increased from 50°C to 95 °C when the cutting speed was increased from 170 to 260 m/min. The high metal removal rate caused high rate of plastic deformation contributing to more heat generation.

4.8 Analysis of Cutting Tool Wear

Maintaining high cutting tool life was the main objectives. While getting high tool life mean reducing tool wear. In double tool turning process test was carried out for 295 s (cutting speed 170-320 m/min, 0.24 mm/rev feed and 1 mm depth of cut) to understand the flank wear of the 1st and 2nd cutting tools. During the machining time of 295s, flank wear was measured at regular intervals with the aid of tool maker's microscope. Figures 4.33 and 4.34 shows the flank wear of both 1st and the 2nd cutting tools. It is found that flank wear of the 2nd cutting tool is lesser due to the heat generated by the 1st cutting tool and reduced coefficient of friction and single cutting tool flank wear also compared with this turning process under the cutting parameters of double tool turning process. The presence of elements such as Manganese and sulphur forms manganese sulphide (MnS) in the work material. It is well known that MnS is a good lubricant. At higher temperature the effectiveness of the lubricant increases. Hence the 2nd cutting tool experiences a lesser flank wear as it is subjected to higher temperatures than the 1st cutting tool and single cutting tool turning. Heck *et al.* (2008) reported the self-lubricating behaviour of MnS inclusion while machining Cast Iron. These MnS inclusions are accumulated on the cutting tool tip and provide an effective lubrication at tool-chip interface. Additionally the MnS inclusions also act as diffusion barrier in reducing the tool wear. It was already reported (Kalidasan *et al.*, 2016) that the equivalent coefficient of friction for the 2nd cutting tool and 1st cutting tool is 0.6 and 0.8, respectively. The 2nd cutting tool experiences a lesser flank wear due to reduced equivalent coefficient of friction. To understand further, cutting tool insert after 295 s of machining was observed under the optical microscope. Figures 4.33, 4.34 and 4.35 show the flank wear of double tool and single tool turning respectively.

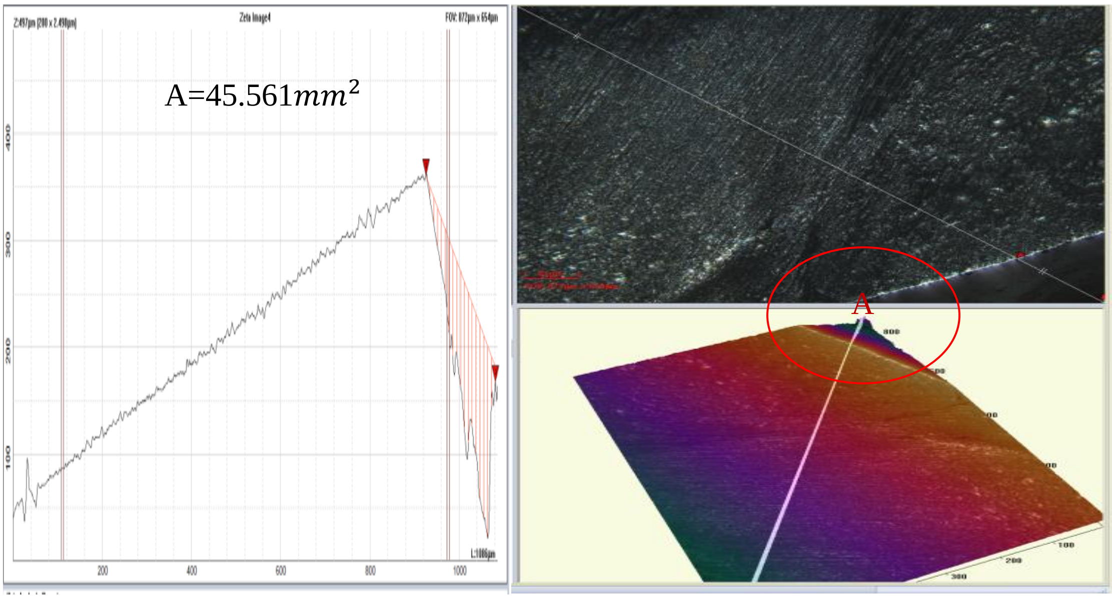

Figure 4.33 Flank wear of the 1st cutting tool at 20X magnification (0.24 mm/rev feed and 1.25mm depth of cut)

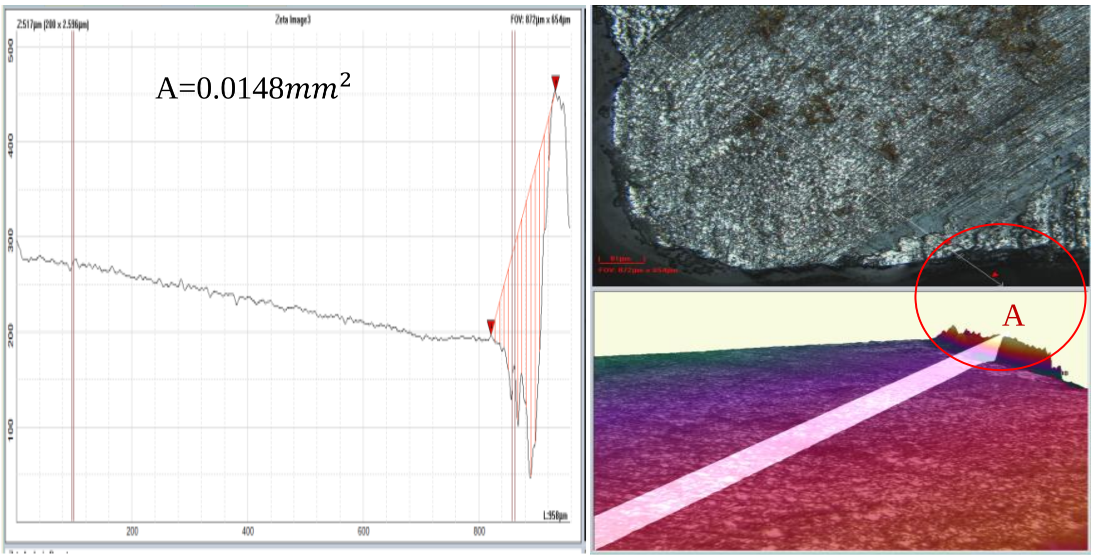

Figure 4.34 Flank wear of the 2nd cutting tool at 20X magnification (0.24 mm/rev feed and 1.25 depth of cut)

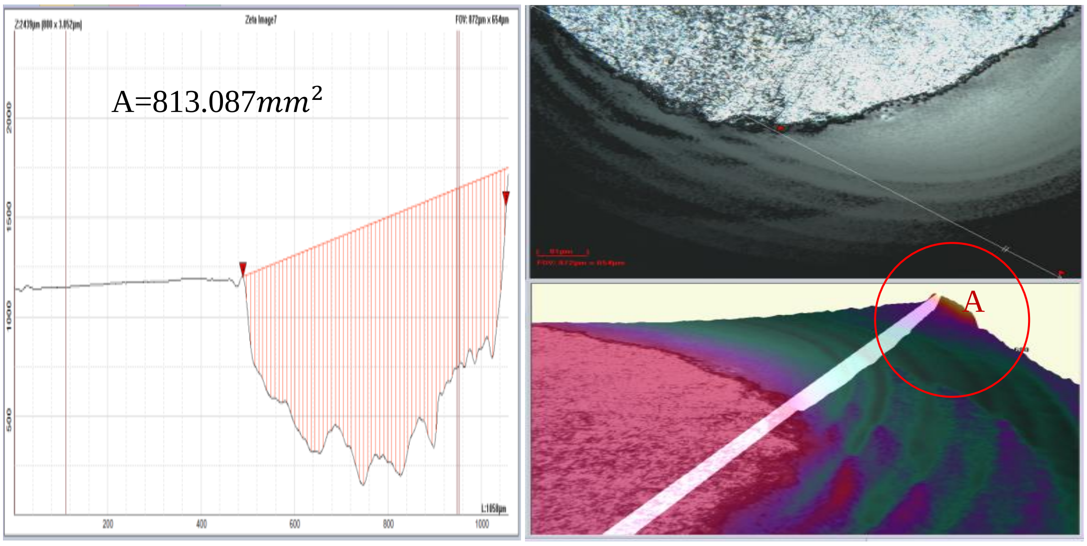

Figure 4.33 Flank wear of the Single cutting tool at 20X magnification (0.24 mm/rev feed and 1 mm depth of cut)

As this study experimental data shows the area damaged in double tools AT1, AT2 and Single Tool turning are 45.561mm^2, 0.0148 mm^2 and 813.087mm^2.Abrasive wear was identified as the dominant mode. Abrasive marks in the direction of workpiece rotation were observed with no traces of adhesive or diffusion wear. Machining by the leading 1st cutting tool raises the workpiece temperature. This temperature rise promotes diffusion wear while reducing abrasion wear. Tool wear was less for measured values for double tool turning. This was between of reduced temperature and shared cutting force among the two cutting tools engaged together.

4.9 Analysis of Chip Morphology

Continuous chips were observed due to ductility mode of the mild-steels and smooth cutting process in double tool turning operation of this study. Compared with single Tool turning process, the upper surface of the chip formed exhibits a pronounced saw-tooth-like structure. Continuous segmented (or serrated) chips can form at high feed rates and at high cutting speeds.

Figure 4.36(a) Shows the chips formed in dry turning process of mild-Steels for all nine different experiments conducted in this study. The maximum and minimum lengths of these chips were identified as the longest is 25mm and the smallest is approximately the size of 6mm which is as shown in the Figure 4.36(b) shows more continues form of chips and bigger size.

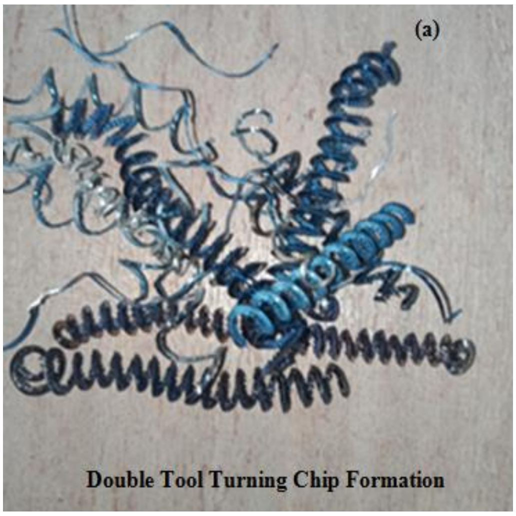

Figure 4.34 Micrograph of chips: (a) Double tool turning

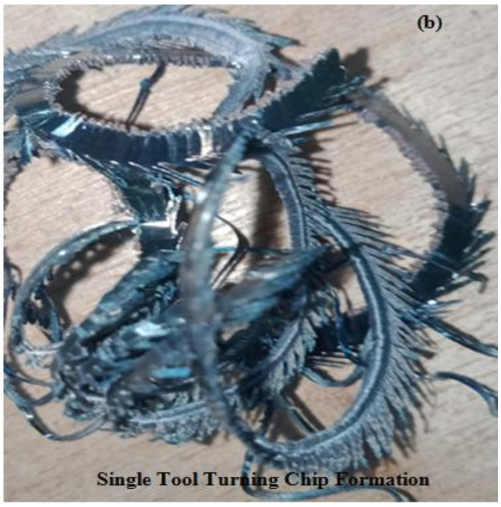

Figure 4.35 Micrograph of chips: (b) Single Tool Turning

CHAPTER -5

CONCLUSIONS AND SCOPE FOR FUTURE WORK

5. 1 Conclusions

In this thesis, experimental investigation was carried out on the double tool and Single tool turning process. The main cutting parameters in this process were cutting speed, feed, and depth of cut. The effect of these cutting parameters on cutting temperature, dimensional error, cutting tool wear, surface roughness, material removal rate, machining time, production rate, chip formation were studied. An analytical and Optimization analysis was developed to estimate the productivity improvement (Production rate) with the compassion of double tool for single tool turning process. The experimental results were matched with the analytically predicted Cutting parameters and parameter factors of productivity improvement for double tool turning process. The cutting temperature, dimensional error, cutting tool wear ,surface roughness, material removal rate, machining time, production rate, chip formation of both double and single tools were investigated. A comparison was drawn between the production rate generated by single tool and double tool turning process. From the results of the analysis, the following conclusions were drawn.

- Double tool turning process proved that productivity was increased as both the 1st and 2nd cutting tool were cutting simultaneously the machining time was reduced there by the material removal rates are increased by 20% in double tool than single tool turning.
- The primary depth of cut did not affect the surface finish significantly during finish or semi finishing process because of the surface quality depends upon the secondary depth of cut in single of double tool process while in single tool turning process the surface is affected. Regardless of this, the surface finish declines during rough cut turning owing to the generation of new surfaces in double tool.
- The combination of a lower feed rate and a smaller secondary depth of cut results in better surface quality.
- Wear of 1st cutting tool exhibits predominant flank wear and very less Area flank wear. However, 2nd cutting tool in the double tool turning exhibits predominantly adhesive and diffusion wear.

- The dimensional error of a machined workpiece was the maximum at the tailstock end and the minimum at the chuck end. This is due to the workpiece deflection caused by the cutting forces (load).
- Chips generated from the double cutting tool did not show any thermal effect, however, chips produced from the Single cutting tool exhibited bending of chip segments due to thermal softening and fracture.
- It was also surprising that material removal rate increased and machining time reduced by 25%.

5.2 Scope for Future Work

In the present work double tool turning process was explored. The work can be extended to other multi-tool machining process.

- A conventional lathe was modified to perform double tool turning process. The feeds of both the cutting tools were same. A separate mechanism can developed such that the different feeds can be given to the two cutting tools. It may help in improving the surface finish.
- In this thesis experimental investigation on double tool turning process was carried out. Numerical study on double tool turning process can be carried out. It further increases the understanding of the process. This will save time and cost by avoiding time consuming and expensive metal cutting experiments

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Reference

1. Lal, G. K. (1996). *Introduction to machining science*. New Age International.
2. Saini, M., Yadav, R. N., & Kumar, S. (2015). An overview on turning process. In *Proceedings of 1st international conference on advancements and recent innovations in mechanical, production and industrial engineering (ARIMPIE-2015)* (Vol. 2, pp. 377-386).
3. Yildiz, A. R. (2012). A comparative study of population-based optimization algorithms for turning operations. *Information Sciences*, *210*, 81-88.
4. Grzesik, W. (2008). Influence of tool wear on surface roughness in hard turning using differently shaped ceramic tools. *Wear*, *265*(3-4), 327-335.
5. Salgado, D. R., & Alonso, F. J. (2006). Tool wear detection in turning operations using singular spectrum analysis. *Journal of Materials Processing Technology*, *171*(3), 451-458.
6. Risbood, K. A., Dixit, U. S., & Sahasrabudhe, A. D. (2003). Prediction of surface roughness and dimensional deviation by measuring cutting forces and vibrations in turning process. *Journal of Materials Processing Technology*, *132*(1-3), 203-214.
7. Mehta, N. K., Pandey, P. C., & Chakravarti, G. (1983). An investigation of tool wear and the vibration spectrum in milling. *Wear*, *91*(2), 219-234.
8. Orhan, S., Er, A. O., Camuşcu, N., & Aslan, E. (2007). Tool wear evaluation by vibration analysis during end milling of AISI D3 cold work tool steel with 35 HRC hardness. *NDT & E International*, *40*(2), 121-126.
9. McCullough, E.M. (1963) 'Economics of multi-Tool lathe operations', *ASME Journal of Engineering for Industry*, Vol. 85, No. 4, pp.402–404..
10. A.Zompi, R.Levi, G.L.Ravignani, Multi-Tool Machining Analysis Part 1 Tool Failure Patterns and Implications. Trans. *ASME J. Engng for Ind.*, 1979, 101, 230-236.
11. G.L.Ravignani, A.Zompi, R.Levi, Multi-Tool Machining Analysis Part 2 Economic Evaluation in view of Tool Life Scatter. Trans. *ASME J. Engng for Ind.*, 1979, 101, 237-240
12. A.K.Sheikh, L.A.Kendall, S.M.Pandit, Probabilistic Optimization of Multitool Machining Operations. Trans. *ASME J. Engng for Ind.*, 1980, 102, 239-246.
13. L.Tang, R.G.Landers, S.N.Balakrishnan, Parallel Turning Process Parameter Optimization Based on a Novel Heuristic Approach. Trans. *ASME J. Manu. Sci. Engng.*, 2008, 130: 031002-1 - 031002-12.

14. E.Ozturk, E.Budak Modelling dynamics of parallel turning operation, *Proceedings of 4 th International Conference on High Performance cutting*, 2010.
15. E.Budak, E.Ozturk, Dynamics and stability of parallel turning operations. *Ann. CIRP, Mfg Technol.*, 2011, 60, 383-386.
16. Tan, F. P., & Creese, R. C. (1995). A generalized multi-pass machining model for machining parameter selection in turning. *The International Journal of Production Research*, *33*(5), 1467-1487.
17. Phan, A.V., Baron.L., Mayer, J.R.R. and Cloutier, G. (2002) 'Finite element and experimental studies of diametral errors in cantilever bar turning', *Applied Mathematics Modelling*, Vol. 27, No. 3, pp.221–232.
18. Killic, B., Cruz, J.A.A. and Raman, S. (2007) 'Inspection of the cylindrical surface feature after turning using coordinate metrology', *International Journal of Machine Tools and Manufacture,* Vol. 47, No. 12–13, pp.1893–1903.
19. Carrino, L., Giorleo, G., Polini, W. and Prisco, U. (2002a) 'Dimensional errors in longitudinal turning based on the unified generalized mechanics of cutting approach: part I: threedimensional theory', *International Journal of Machine Tools and Manufacture*, Vol. 42, No. 14, pp.1509–1515.
20. Carrino, L., Giorleo, G., Polini, W. and Prisco, U. (2002b) 'Dimensional errors in longitudinal turning based on the unified generalized mechanics of cutting approach: part II: machining process analysis and dimensional error estimate', *International Journal of Machine Tools and Manufacture*, Vol. 42, No. 14, pp.1517–1525.
21. Jianliang, G. and Rongdi, H. (2006) 'A united model of diametral error in slender bar turning with a follower rest', *International Journal of Machine Tools and Manufacture*, Vol. 46, No. 9, pp.1002–1012.
22. Mayer, J.R.R., Phan, A.V. and Cloutier, G. (2000) 'Prediction of diameter errors in bar turning: a computationally effective model', *Applied. Mathematics Modelling*, Vol. 24, No. 12, pp.943–956.
23. Benardos, P.G., Mosialos, S. and Vosniakos, G.C. (2006) 'Prediction of workpiece elastic deflections under cutting forces in turning',*Robotics and Computer Integrated Manufacturing*, Vol. 22, Nos. 5–6, pp.505514.
24. Risbood, K.A., Dixit, U.S. and Sahasrabudhe, A.D. (2003) 'Prediction of surface roughness and dimensional deviation by measuring cutting forces and vibrations in

turning process', *Journal of Materials Processing Technology*, Vol. 132, No. 1, pp.203–214.

25. Shashikant, J., Asim, T. and Suhas, J. (2013) 'Influence of preheating on chip segmentation and microstructure in orthogonal machining of ti6Al4V', *ASME Journal of Manufacturing Science and Engineering*, Vol. 135, No. 6, p.061017.
26. Katuku, K., Koursaris, A. and Sigalas, I. (2009) 'Wear, cutting forces and chip characteristics when dry turning ASTM grade 2 austempered ductile iron with pcBN cutting tools under finishing conditions', *Journal of Materials Processing Technology*, Vol. 209, No. 5, pp.2412–2420.
27. Y. Lee, "Cutting parameter selection for maximizing production rate or minimizing the production cost in multistage turning operations" Journal of Material Processing Technology in 6th Feb, 1999
28. 28.Tang, L., Landers, R. G., & Balakrishnan, S. N. (2008). Parallel turning process parameter optimization based on a novel heuristic approach. *Journal of manufacturing science and engineering*, *130*(3).
29. El-Hossainy, T. M. (2010). Enhancement of surface quality using a newly developed technique in turning operations. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *224*(9), 1389-1397.
30. Budak, E., & Ozturk, E. (2011). Dynamics and stability of parallel turning operations. *CIRP annals*, *60*(1), 383-386.
31. Deepak, S. S. K. (2012). Cutting speed and Feed Rate Optimization for minimizing production Time of Turning process. *International Journal of Modern Engineering Research (IJMER)*, *2*(5), 3398-3401.
32. Ozturk, E., Comak, A., & Budak, E. (2016). Tuning of tool dynamics for increased stability of parallel (simultaneous) turning processes. *Journal of Sound and Vibration*, *360*, 17-30.
33. Yadav, R. N. (2017). A hybrid approach of Taguchi-Response surface methodology for modeling and optimization of duplex turning process. *Measurement*, *100*, 131-138.
34. Dewes, R. C., Ng, E., Chua, K. S., Newton, P. G., & Aspinwall, D. K. (1999). Temperature measurement when high speed machining hardened mould/die steel. *Journal of Materials Processing Technology*, *92*, 293-301.

35. Sutter, G., Faure, L., Molinari, A., Ranc, N., & Pina, V. (2003). An experimental technique for the measurement of temperature fields for the orthogonal cutting in high speed machining. *International Journal of Machine Tools and Manufacture*, *43*(7), 671-678.
36. Karpat, Y., & Özel, T. (2008). Analytical and thermal modeling of high-speed machining with chamfered tools. *Journal of Manufacturing Science and Engineering*, *130*(1).
37. Sarma, D. K., & Dixit, U. S. (2009). Environment-friendly strategies for efficient utilization of cutting tools in finish turning. *Journal of manufacturing science and engineering*, *131*(6).
38. Nalbant, M., Gökkaya, H., Toktaş, İ., & Sur, G. (2009). The experimental investigation of the effects of uncoated, PVD-and CVD-coated cemented carbide inserts and cutting parameters on surface roughness in CNC turning and its prediction using artificial neural networks. *Robotics and Computer-Integrated Manufacturing*, *25*(1), 211-223.
39. Correia, A. E., & Davim, J. P. (2011). Surface roughness measurement in turning carbon steel AISI 1045 using wiper inserts. *Measurement*, *44*(5), 1000-1005.
40. Ramesh, S., Karunamoorthy, L., & Palanikumar, K. (2012). Measurement and analysis of surface roughness in turning of aerospace titanium alloy (gr5). *Measurement*, *45*(5), 1266-1276.
41. Günay, M., & Yücel, E. (2013). Application of Taguchi method for determining optimum surface roughness in turning of high-alloy white cast iron. *Measurement*, *46*(2), 913-919.
42. Cakir, M. C., Ensarioglu, C., & Demirayak, I. (2009). Mathematical modeling of surface roughness for evaluating the effects of cutting parameters and coating material. *Journal of materials processing technology*, *209*(1), 102-109.
43. BHUSHAN, B. 2001. Modern tribology handbook, Boca Raton, FL, CRC Press
44. Abukhshim, N. A., Mativenga, P. T., & Sheikh, M. A. (2004). An investigation of the tool-chip contact length and wear in high-speed turning of EN19 steel. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *218*(8), 889-903.
45. List, G., Sutter, G., & Bi, X. F. (2009). Investigation of tool wears in High Speed Machining by using a ballistic set-up. *Wear*, *267*(9-10), 1673-1679.

46. Mayer, J. R., Phan, A. V., & Cloutier, G. (2000). Prediction of diameter errors in bar turning: a computationally effective model. *Applied Mathematical Modelling*, *24*(12), 943-956.
47. Bodi, C., & Rongdi, H. (2007). Numerical modelling of diameter errors in slender bar turning with movable support. *Communications in numerical methods in engineering*, *23*(10), 961-972.
48. Wang, S. G., & Hsu, Y. L. (2005). One-pass milling machining parameter optimization to achieve mirror surface roughness. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *219*(1), 177-181.
49. Abburi, N. R., & Dixit, U. S. (2007). Multi-objective optimization of multipass turning processes. *The International Journal of Advanced Manufacturing Technology*, *32*(9-10), 902-910.
50. Usubamatov, R., Zain, Z. M., & Ahmed, A. M. (2011). Productivity rate of machine tools depending on the change of machining modes. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *225*(8), 1447-1456.
51. Kalpakjian, S., Schmid, S., & Design, D. (2006). Manufacturing. *Engineering and Technology SI 6th Edition-Serope Kalpakjian and Stephen Schmid: Manufacturing, Engineering and Technology: Prentice Hall*.
52. Boothroyd, G., & Knight, W. A. Fundamentals of machining and machine tools, 1989. *Reproduced with permission of the copyright owner. Further reproduction prohibited without permission*.
53. Kalpakjian, S., & Schmid, S. R. (2003). Manufacturing processes for engineering materials, and systems. *Material Removal Process: Cutting, 4th ed., Pearson Education, Upper Saddle River, NJ*, 452.
54. Childs, T. H., Maekawa, K., Obikawa, T., & Yamane, Y. (2000). *Metal machining: theory and applications*. Butterworth-Heinemann.
55. Stephenson, D. A. (1993). Tool-work thermocouple temperature measurements—theory and implementation issues.
56. Jaharah, A. G., Rodzi, M. N. A. M., Rahman, A., Rahman, M. N. A., & CH, C. H. (2009). Machinability of FCD 500 ductile cast iron using coated carbide tool in dry machining condition. *International Journal of Mechanical and Materials Engineering*, *4*(3), 279-284.

57. Yanda, H., Ghani, J. A., Rodzi, M. N. A. M., Othman, K., & Haron, C. H. C. (2010). Optimization of material removal rate, surface roughness and tool life on conventional dry turning of FCD700. *International Journal of Mechanical and Materials Engineering*, *5*(2), 182-190.
58. Usubamatov R, Ismail KA, Sah ZM (2013) Mathematical models for productivity and availability of automated lines. Int J Adv Manuf Technol 66(1):59–69
59. D.A. Stephenson, A. Ali, Tool temperatures in interrupted metal cutting, J. Eng. Ind. 114 (1992) 127–136.
60. Heck, M., Ortner, H.M., Flege, S., Reuter, U. and Ensinger, W. (2008) 'Analytical investigations concerning the wear behavior of cutting tools used for the machining of compacted graphite iron and grey cast iron', *International Journal of Refractory Metals and Hard Materials,* Vol. 26, No. 3, pp.197–206.
61. Kalidasan, R., Yatin, M., Sarma, D.K., Senthilvelan, S. and Dixit, U.S. (2016) 'An experimental study of cutting forces and temperature in multi-tool turning of grey cast iron', *International Journal of Machining and Machinability of Materials* (In press).