OPTIMIZATION OF CUTTING PARAMETERS FOR DRY TURNING OF FLAKE GRAPHITE CAST IRON MATERIAL

A thesis submitted by

Kemal Wata Tume

PGR/19503/12

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Of

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SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

DEPARTMENT OF MECHANICAL DESIGN AND MANUFACTURING ENGINEERING.

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Under the Supervision & Guidance of

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DECLARATION

I hereby declare that the work, which is being presented in the thesis, is entitled "**Optimization of cutting parameters for dry turning of Flake graphite cast iron material.**" In partial fulfillment of the requirement for the award of the Degree of Masters of Science in Manufacturing Engineering is my work carried out September 2020 to June 2021 under the supervision and guidance of **Dr. Moera Gutu Jiru;** Assistant Professor 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 suitably acknowledged.

Kemal Wata Tume ____________________ ____________________

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 Jiru ____________________ ____________________

Advisor Signature Date

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ABBREVIATIONS

ANOVA: Analisis of variance

CBN: Cubic boron nitride

CGI: Compacted Graphite Iron

CNC: Computer numerical control

CW: Crater wear

DOE: Design of experiment

ECEA: End cutting edge angle

ERA: End relief angle

Fc: cutting force

FGI: Flake graphite cast iron

FW: Flank wear

HSS: High-speed steel

MQL: Minimum quantity lubrication

Ra: Average surface roughness

SCEA: Side cutting edge angle

SGI: Spheroidal Graphite Iron

SRA: Side relief angle

THMS: Online tool monitoring system

TiN: Titanium nitride

TTL: Taylor tool life

Abstract

Nowadays, material development is focused on the continuous enhancement of a material's property. To lower machining costs, fabricators commonly order materials with superior machinability properties while with mechanical and physical properties that are unchanged. Turning of dry Flake graphite cast iron on conventional lathe machine is applicable in the industry for many purposes. However, due to segmented chip formation machinability of this material is difficult. In this research Optimization of machinability of dry Flake graphite cast iron using conventional machining was conducted to obtain optimum surface finish. Study optimum cutting parameters for achieving minimum surface roughness, investigate tool life, and factors that affect tool life. Dry turning operation is very important for saving the cost of cutting fluid; contribute to a clean environment and is good for the safety of machinists. Identifying Flake graphite Cast iron Chips producing for all grades of Flake graphite cast irons are segmented and discontinuous which causes difficulty to maintain a good surface finish. The effect of cutting parameters optimized for dry turning process using DOE. The effect of Tool wears studied qualitatively for each optimized parameter. Chip morphology was studied for observation of machinability at optimized cutting parameters. Machining operations for dry turning particularly Flake graphite cast iron materials on conventional machining (turning) and at optimized of cutting parameters good surface finish was achieved. For the effect of cutting speed 55m/min, the Ra value was 1.97µm, feed of 0.3mm/rev has 1.97µm, Ra value and depth of cut of 0.5mm, the Ra value 2.24 µm obtained at optimized parameters experimentally. The result of variance (ANOVA) indicates that the contribution of cutting speed, feed, and depth of cut were 72.93%, 24.62%, and 1.75% respectively. The cutting speed was the most significant factor for improving surface roughness.

Keywords: *ANOVA, cutting tool, dry turning, Flake graphite cast irons. Machining, temperature, tool wear.*

CHAPTER ONE

Introduction

1.1.Back ground of the study

Machining is a material removal process where a cutting tool is made of a harder material than the workpiece is using to remove materials in the conventional machining process. It is not only performing for the overall forming of parts into their ultimate shapes but also it is used to convert castings, forgings, or preformed blocks of metal into desired shapes, with size and finish specified to fulfills design requirements [1]. Operations that can be done on a lathe machine are turning, facing, counter turning and tapering, boring and chamfering. Turning operation is a very important material removal process in modern industry. At least one-fifth of all applications in metal cutting are covered by turning operation. It is used to reduce the diameter of the workpiece, usually to a specified dimension, and to produce a smooth finish on the metal [2]. Machinability, generally, is defining in terms of surface finish, tool life, force and power requirements, and chip control. The machinability of materials depends on their work, properties, and microstructure [4]. Thus, proper selection and control of process variables were important. Optimization of machining processes was usually dependent on operating conditions, which minimize machining costs and maximize production rate[44]. The three important process parameters in this study were the depth of cut, feed, and cutting speed. The surface roughness of a turned workpiece is dependent on these process parameters. The best green machining performance of cast iron can be achieved by choosing an appropriate cutting tool type and condition, like a suitably coated tool, higher cutting speed, and low feed rate and depth of cut [5]. In addition, it also depends on several other exogenous factors such as workpiece material and tool material type. Mechanical properties, quality, and type of the machine tool used auxiliary tooling Surface roughness remain the main indicator of machined component quality as it was related to surface quality[45]. The difficulty of all industrialists for achieving high-quality products with more productivity within less machining time affects surface roughness during the turning of Flake graphite cast iron[10]. Even rough surfaces wear more quickly and have high friction coefficient than smooth surfaces. As the surface roughness increases, the quality of a product goes on the decrease. Therefore, it should association the gap between quality and efficiency. Dry machining is now of grand interest and in fact, they meet with achievement in the field of environmentally responsive manufacturing[45]. The optimization of turning process parameter in dry turning of Flake graphite cast iron by using carbide inserts studied [6]. The result showed that cutting speed is the most dominant factor which affected surface roughness and followed by feed and depth of cut. At low and moderate speeds, feed marks were observed whereas at higher speeds feed marks were absent.

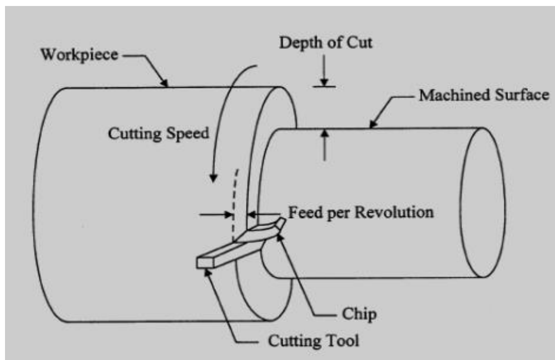

Figure 1. Schematic representation of turning operation[3].

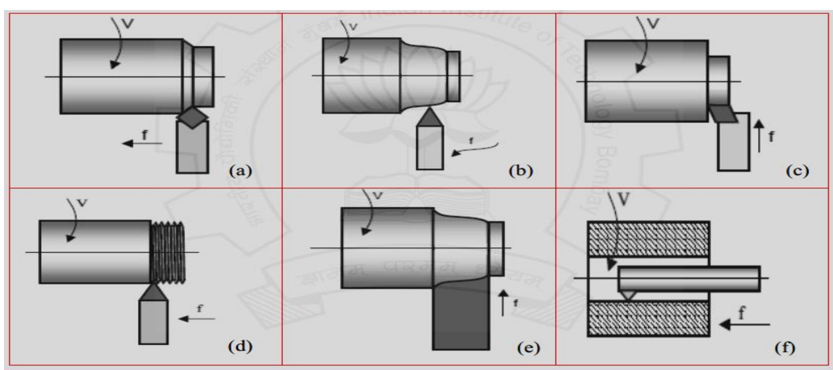

Figure 2. Different types of Turning Operations[straight turning(a), Contour turning and Taper turning(b), facing(c), Thread cutting(d), form turning(e) and boring(f)[4]

The dry turning process is very important since it contributes to a clean environment and safety for the operator. Many scientists have suggested the optimization of the dry turning process for different materials. The main objective of using cutting fluids in machining operations is the reduction of temperature in the cutting region to increase tool life. However, the advantages offered by cutting fluids have been strongly debated because of their negative effects on the economic aspect, the environment, and the health of workers using them. A trend to solve these problems is cutting without fluid, a method named dry cutting, which has been made possible due to technological innovations. The study focused on the surface integrity and wear mechanisms associated with the mechanical turning of cast iron under dry and wet cutting conditions was investigated. The result showed that the tool wear can be attributed to high chip contact length, higher temperatures, high adhesion, and diffusion in wet cutting in assessment to dry cutting. Mechanical properties make a great involvement to surface roughness formation in ultra-precision machining due to the "size effect" and for different isotropic materials, the machined surface roughness under the same cutting conditions is different [7]. The selection of appropriate tool materials depends not only on the material to be machined but also on process parameters and the characteristics of the machine tool [8]. Surface roughness is highly affected by cutting parameters during the turning process on a conventional lathe machine. These parameters must be within the recommended range depending on the type of material to be machined, tool geometry, and tool material [9]. In this study machining of Flake graphite cast iron was a waste of modern manufacturing, by using different lubricants and cutting fluids during machining operations. There were many applications where cutting is carried out dry, in air, with no advantage being found in the use of cutting fluid. For example, many turning and facing operations used carbide tools were carried out dry, the cost of fluid being avoided. extremely many operations on Flake graphite cast iron require no cutting fluid. Environmentally-friendly metal chips, elimination [15]. Disadvantages of fluids were, it may be toxic or offensive to the operator; it could be a fire hazard; it may be harmful to the lubricating system of the machine tool; it corroded or discolor the work material; Environmental effects and health hazard to operator avoided by using dry machining technique to overcome effects of coolant such as environmental pollution, health hazard, treatment and cleaning cost. The main concern during the machining of Flake graphite cast iron is to obtain a better surface finish.

1.2.Machinability of Cast iron Alloys

Flake graphite cast irons are considered to have very good machining qualities. A major reason for the continued large-scale use of cast iron in engineering is not only the low cost of the material and the casting process but also the economics of machining the finished component. By nearly all criteria cast iron has good machinability: low rates of tool wear, high rates of metal removal, relatively low tool forces, and low power consumption. The surface of the machined cast iron is rather not shiny, but best for many sliding interfaces. The chips are produced as very small waste which can readily be cleared from the cutting area even when machining at very high speeds. It is a small piece dirty and sandy operation, throwing a fine spray of graphite into the air, so that shield for factory personnel may be required. As when cutting other materials, there is a great dissimilarity between the behaviors of cast iron when sheared

On the shear plane and

At the tool work interfaces.

The most important characteristic is that fracture on the shear plane occurs at very frequent intervals, initiated by the graphite flakes. The chip is thus composed of very small remains a few millimeters in length. Because the chips are not continuous, the length of getting in touch with the rake face is very short. The chips are thin and the cutting force and power consumption are low. The cutting force is low also because graphite flakes are very weak. One flake may extend a noticeable way across the shear plane. Table 1 shows values for the cutting force (Fc) for typical pearlitic cast iron in comparison with steels.

Table 1. Cutting forces: pearlitic, flake-graphite cast iron versus mild steel. Feed: 0.16 mm rev-1 Depth of cut: 1.25 mm [10].

Cutting speed	Cast iron forces		Mild steel forces	
	F_c	F_f	F_c	F_f
m min^{-1}	(N)	(N)	(N)	(N)
30	222	232	520	356
61	245	285	490	364
91	245	320	445	325
122	267	338	422	313

This aspect of machinability is inclined by the grade and masterpiece of the cast iron. Low strength cast irons, the structure of which consists mainly of ferrite and graphite, are the most machine able, permitting the highest rates of metal removal [13]. Permissible speeds and feeds are somewhat lower for pearlitic irons, and decrease as the strength and hardness are raised. As with steel, there are extensive published data for cutting speeds when machining gray cast iron with high-speed steel and cemented carbide (WC- Co) tools. Recently, there is much data for ceramic tools [15]. Table 2 shows typical recommendations for turning gray cast irons. These are confidential according to hardness when using the three classes of tool material. The use of ceramic (alumina and sialon) tools for machining cast iron has increased greatly in recent years, Main in mass production turning, boring and milling operations. Most cast-iron brake drums, clutch faces, and flywheels are today, being machined with ceramic tools. The excellent surface finish achieved often eliminates the need for a grinding operation. Because the chips are disjointed, very high cutting speeds can be used without problems with chip control.

Table 2.Typical maximum turning speeds for flake graphite cast iron [48].

Hardness	High-speed steel tools	Cemented carbide (WC-CO) tools	Ceramic (alumina or sialon tools)
	Feed .5 mm/rev	Feed .5 mm/rev	Feed .5 mm/rev
(BHN)	(m min^{-1})	(m min^{-1})	(m min^{-1})
115-200	40	120	450
150-200	25	90	400
200-250	20	70	250
250-300	12	55	180

By contrast, the highly alloyed irons and chilled irons, with very little graphite and containing large amounts of iron carbide (Fe_3C) and other metal carbides, become very difficult to machine. Chilled iron rolls may be machined only at speeds of the order of 3 to 10 m min^{-1} with cemented carbide tools. advanced speeds can be used with ceramic or cubic boron nitride tools. Alumina tools are suggested for use on chilled cast iron of hardness (430 HV) at about 50 m min^{-1}. Turning operations are being carried out with cubic boron nitride tools on chilled iron with hardness 55-58 RC (600-650 HV) at about 80 m min^{-1} at feeds up to 0.4 mm/rev [10].

1.3 Surface Roughness, Surface Finish, and Surface integrity

The functional show of any solid surface depends on the physical conditions and chemical work of the concerned surface and subsurface layers. The quality of the surface of manufactured products by different machining processes is commonly defined by Surface roughness, surface finish, and surface integrity. From time to time they are used interchangeably, but they are not the same. Roughness and finish imply the same thing but in a different way; while integrity has a wide-ranging domain and encompasses the former two [11].

1.3.1 Surface Finish

The smoothness of a surface is resolute by the surface finish. It is a roundabout way that indicates the height and depth of asperities of the solid surface. No surface is perfectly smooth; even if it is perfectly smooth, it cannot be determined as every measuring instrument has a range of its facility. High surface finish is mandatory in the following fields; optics and electronics (lenses, mirrors), medical instruments, microfluid (nozzle, channel, mixture), and material properties with high exhaustion life, wear resistance, and toughness [12].

1.3.2 Surface Roughness

Surface roughness is the quantitative approach of determining the softness of a surface by measuring the height of peaks and depth of valleys over a fixed length. There are various principles of measuring surface roughness. The studied responses were arithmetic mean of roughness parameter(Ra), root mean square surface roughness parameter(Rq), ten-point mean roughness parameter (Rz), the maximum height of the profile parameter (Rt). Whatever be the case, roughness can quantitatively determine the profile of a solid surface and is one crucial parameter of surface grain. Unlike surface roughness, surface finish is one qualitative approach to representing the smoothness of a surface. Roughness and finish are inversely comparative. When a surface finish is good, its surface roughness is also reduced. Surface roughness was measured by equipment called a profilometer which gives the value of surface roughness with micrometers [13].

1.3.3 Surface Integrity

Surface integrity encompasses all of the elements that describe all conditions of existing solid surface which is produced by unrelated machining practices. It describes not only the topological (geometric) features of surfaces and their physical and chemical properties, but also their usual and metallurgical properties and characteristics. Every surface generation or modification process is associated with the amendment of various properties together with roughness, plastic deformation, micro-cracking, phase transformations; micro-hardness, and remaining stress. Several surface defects produced and caused by different factors during turning action can be responsible for insufficient surface integrity. These defects usually are caused by one or a combination of the following factors as [14].

- Defects in the imaginative material
- How the surface is produced
- Inappropriate control of the process parameters.

The following are general definitions of defects in the turning process of various components:

Cracks may be external or internal. Craters are shallow depressions that are created on the surface of machined parts. The intergranular knock is the failure of grain limits during liquid metal embrittlement and corrosion. Pits are shallow surface depressions, usually the result of chemical or physical attacks. Residual stresses are tension on the surface that is caused by non-uniform deformation and non-uniform temperature distribution during the machining process. Surface plastic deformation is a severe surface warp caused by high stresses due to factors such as friction, tool and dies geometry, worn tools, and processing methods. The reasons for calculating surface texture are to improve the service life of the components, to improve the fatigue resistance, to reduce initial wear of parts, and to have a close dimensional tolerance of the parts.

1.4 Types and Applications of cast iron Alloys

The major application of cast irons in the automotive industry (brake drums and disks, exhaust manifolds, cylinder heads, and especially engine blocks, including diesel engines) and gives rise to the need for further improvement in research and innovation, which aims to better, understand the performance of these materials before the various types of fabrication processes. Basement for machine tools, parts of highway machines (articulated trucks, dozer blades, draglines, compactors, asphalt pavers, etc.), pumps for miner industries, among others, are applications of diverse types of cast iron [15]. The most common types of flake-graphite cast iron grades that are used widely in different applications are the following.

1.4.1. Pearlitic Flake Graphite Iron (FGI)

High-alloy graphitic irons are used primarily for applications requiring corrosion resistance or a combination of strength and oxidation resistance. They are produced in both flake graphite (gray iron) or spheroidal graphite (ductile iron)[16].

1.4.2. Compacted Graphite Iron (CGI)

Compacted graphite cast iron is a more up-to-date material. It is possible to obtain the crude molten state, by adding alloying elements, the so-called vermicular graphite, which is halfway between flakes and nodules. The material from the point of view of the chemical composition range shows no significant difference from gray and nodular cast irons (each containing about 94% iron, 3% carbon, 2.5% silicon, and the leftovers are divided among alloying and remaining elements). The main differences between these alloys are due to their types of graphite morphologies, which give different physical and mechanical properties to each. The process of obtaining the vermicular graphite is employing the magnesium action, which is a nodulizing element, present in a range of 0.01 to 0.02% [15]. Compacted graphite cast iron is characterized by graphite that is interconnected within eutectic cells, as is the flake graphite in gray iron. Compared with the graphite in gray iron, however, the graphite in CG iron is coarser and more rounded, i.e., its structure is in-between the structures of gray iron and ductile iron [16].

1.4.3. Spheroidal Graphite Iron (SGI)

The main effects of chemical composition are similar to those described for gray cast iron. The quantitative differences in the extent of these effects and qualitative differences in the influence on graphite morphology [16].

1.5. Structure of the Thesis

This thesis entitled Optimization of cutting parameters for dry turning of Flake graphite cast iron material has five chapters. These are introduction, definition, basic values, machining route, and others. Chapter 2 presents related literary works on challenges of machining of different materials, basic concepts of turning process, the problem of the statement, Research gap, objectives, significance of the study, scopes, and limitations of the study. Chapter 3 discussed the experimental procedures, equipment, and materials used for the study. Chapter 4 presents the result and discussion of major findings of this experimental work. Chapter 5 discussed or summarizes the study; conclusions, suggestions, and future research directions.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

There are two main practical problems that engineers face in the manufacturing process. The first is to determine the values of the process parameters which yield the desired product quality (meet technical specification) and the second is to maximize manufacturing system performance using the available resources. The decisions made by manufacturing engineers are based on conventions regarding the phenomena that take place during processing. In the turning process, many of these phenomena are highly complex and interact with a large number of factors, thus preventing high process performance from being attained.

To overcome these problems, the researchers propose models that try to replicate the conditions during turning and establish cause and effect relationships between various factors and desired product characteristics. The optimization of the turning process has been the object of technological research for some decades now. This chapter is to presents the various methodologies and strategies that are adopted by researchers in turning optimization and different techniques used by the researchers in multi-objective optimization in the turning process.

2.2 Basic Concepts of Turning Process

One of the most basic machining processes is the turning process, which is processed on a lathe machine by rotating the workpiece through a spindle and machined the parts by using the cutting tool which has a high strong point and hardness than that of workpiece materials. The starting material is generally a workpiece that has been made by other processes such as casting, forging, extrusion, drawing, or powder metallurgy. Generally turning process using lathe machine is:

- to creates cylindrical external or internal shapes
- to creates, flat surfaces on part ends (faces)
- a single-point cutting tool
- to create a wide range of shapes and

As shown in Figure 3.turning is performed at various (1) revolving speeds (N) of the workpiece clamped in a spindle, (2) pits of cut (d) and (3) feeds (f) depending on the workpiece materials, cutting-tool materials, surface finish and dimensional accuracy required and characteristics of the machine tool. The cutting speed is the speed of the work as it rotates past the cutting tool [43]. The feed rate is the rate at which the tool advances into the work. The depth of cut is the amount of material removed as the work revolves on its axis.

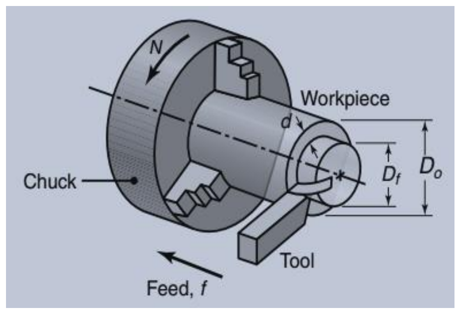

Figure 3.Schematic illustration of the basic turning operation, showing a depth of cut (d); feed (f), and spindle rotational speed (N) source [17]

The turning process is a process in which, a single-point turning tool moves axially along the side of the workpiece, removing material to form different features including steps, tapers, chamfers, and contours. These features are typically machined at a small radial depth of cut and multiple passes are made until the end diameter is reached.

2.2.1 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 capacity from the initial and final weight of the 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 expanse, the tool travels in one revolution (feed, f) and the depth of cut (d). The unit of material removal rate is $(mm^3/_{min})$ or $(in^3/_{min})$. The volume of this ring is the product of the cross-sectional area (f) (d) and the average circumference of the ring $\pi D_{avg,}$

where

$$D_{avg} = \frac{D_0 + D_i}{2} \qquad (2.1)$$

$$d = \frac{D_0 - D\text{i}}{2} \quad (2.2)$$

The rotational speed of the workpiece is N and the material removal rate per

Revolution is $\pi \text{D}_{\text{avg}}(f)(d)$ since there are N revolutions per minute and the

The removal rate is given by:

$$MRR = \pi D_{avg} dfN \quad (2.3)$$

$MRR = dfV$ Were V (cutting speed) $=\pi D_{avg} N$

The cutting time t, for a workpiece of length l can be calculated by noting that the tool

Travels at a feed rate of $fN = \left(\frac{mm}{rev}\right)\left(\frac{rev}{min}\right) = \frac{mm}{min}$ since the distance traveled is $l$mm,

The cutting time can be given by equation (2.4):

$$t = \frac{l}{fN} \quad (2.4)$$

Cutting force is a key performance parameter in which directly affects the turning process. Some factors like tool breakage, tool wear, and workpiece deflection are mainly developed due to cutting force fashioned during the machining process. Three principal forces acting on a cutting tool during the turning process are cutting force (F_c), thrust force (F_t), and radial force (F_r) as shown in Figure 4.

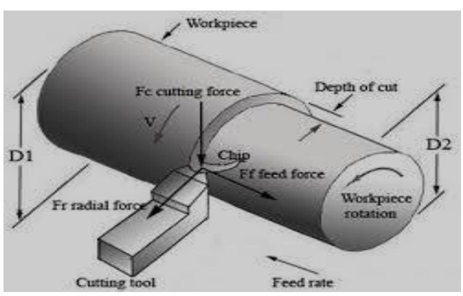

Figure 4. Tool geometry parameters on cutting force [18].

The cutting force acts downward on the tooltip and thus tends to draw away the tool downward and the workpiece uphill and it supplies the energy required for the cutting operation during the process. The ratio of F_c to the cross-sectional area being cut is called a specific cutting force. The push force acts in the longitudinal direction. It is 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 consequential forcer and radial force acts on the cutting tool perpendicular to cutting force. The cutting force used in this study was calculated from equation (2.5) for the turning operation.

$$P_{net} = \frac{F_c{}^* V_c}{60000} \tag{2.5}$$

Where, F_c- cutting force, P_{net}- net machine power in KW, V_c- cutting speed in m/min

2.2.2 Tool Life and the Taylor Tool Life Equation

As the cutting process proceeds the various wear mechanisms result in increasing levels of wear on the cutting tool, as the general connection of tool wear versus cutting time is shown in Figure 5. Three regions can usually be identified in the typical wear enlargement curve. The first is the break-in period in which the sharp cutting-edge wears go rapidly at the beginning of the cutting process and it occurs within the first few minutes of cutting. The break-in period is followed by wear that occurs at a somewhat uniform rate which is called the steady-state wear region. Finally, wear reaches a level at which the wear rate starts to raise speed. This marks the beginning of the malfunction region, in which cutting temperatures are higher and the general efficiency of the machining process is reduced. If allowed to continue, the tool finally fails by temperature failure. Although the bond shown is for flank wear, a similar relationship occurs for crater wear.

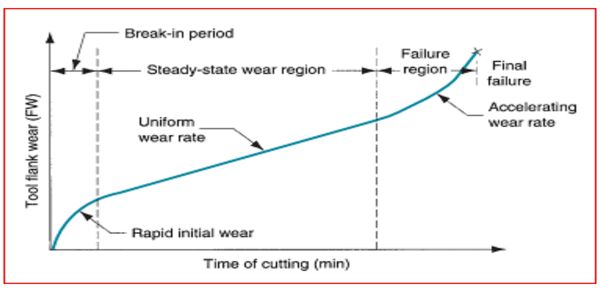

Figure 5. Tool wear as a function of cutting time. Flank wear (FW) is used here as the measure of tool wear, Crater wear follows a similar growth curve [19].

Tool life is defined as the length of cutting the time that the tool can be worn. Operating the tool until the final catastrophic crash is one way of defining tool life. However, in making, it is often a disadvantage to using the tool until this collapse occurs because of difficulties in re-sharpening the tool and problems with work surface quality. As an alternative, a level of tool wear can be selected as a reason for tool life and the tool is replaced when wear reaches that level. Taylor tool life can be articulated in equation form as follows [19].

$$VT^n = C \tag{2.6}$$

Where, v-cutting speed, m/min; T- tool life, min; and n and C are parameters whose values depend on feed, depth of cut, workpiece material, tooling (material in particular), and the tool life criterion used.

To appreciate the importance of the exponent, n, Taylor tool life equation can be rearranged as:

$$T = \left(\frac{C}{V}\right)^{\frac{1}{n}} \tag{2.7}$$

Thus, for constant *C:* smaller *n*⇒ smaller tool life

For turning, equation (2.6) can be modified to

$$VT^n \, \mathrm{d}^x f^y = C \tag{2.8}$$

Where,

d = depth of cut (mm)

f = feed of the tool (mm/rev)

x, y: must be determined experimentally for each cutting condition

And equation (2.8) is rearranged as;

$$T = C^{1/n} V^{-1/n} \, \mathrm{d}^{-x/n} f^{-y/n} \tag{2.9}$$

2.2.3 Tool Wear

Machining operations like turning, drilling, milling are accomplished using cutting tools. There are three likely modes by which a cutting tool can fail in the machining process due to different circumstances, which are described as follows.

Fracture failure

This mode of crash occurs when the cutting force at the tool point becomes excessive, causing it to fail suddenly by easily broken fracture.

Temperature failure: This collapse occurs when the cutting temperature is too high for the tool material, causing the material at the tool point to soften, which leads to a plastic buckle and loss of the sharp edge.

Gradual wear: The gradual wearing of the cutting-edge causes' loss of tool shape, a decline in cutting efficiency, and speeding up of wearing as the tool becomes heavily worn and finally tool failure like a temperature malfunction. During the machining process, wear marks will appear on the tool. The extent of tool wear will depend on the stresses to which the tool is subjected. Gradual wear marks appear on the major and minor flanks of the cutting tool where it makes contact with the workpiece and on the tool face where it is in contact with the chip being removed[48]. Accordingly, two main types of tool wear can be distinguished: crater wear and flank wear. As a rule, the greater the amount of wear, the greater the mechanical and thermal stress experienced by the tool. To give an explanation of tool wear and the mechanisms that cause it a single-point cutting tool was used. Crater wear consists of a cavity in the rake face of the tool that forms and grows from the action of the chip sliding against the facade. High stresses and temperatures characterize the tool–chip contact crossing point, contributing to the wearing action. The crater can be considered either by its distance downward or its area. Flank wear occurs on the flank or the relief face of the tool. It results from rubbing between the newly generated work surface and the flank face adjacent to the cutting edge. Flank wear is measured by the width of the wear,b and, FW.

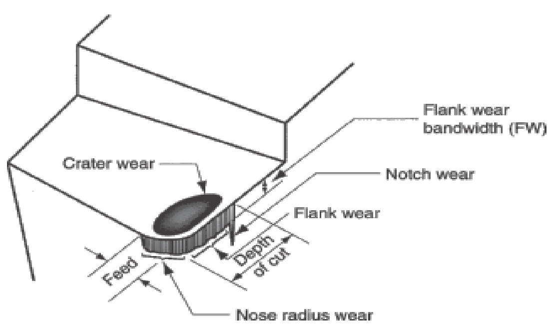

Figure 6. Diagram of worn cutting tool, showing principal locations and wear types [19].

his group of wear is sometimes called the flank wear land. Certain features of flank wear can be well-known. First, an extreme condition of flank wear often appears on the cutting edge at the spot corresponding to the original float-up of the work part. This is called notch wear.

2.3. Recommended Cutting Parameters of flake graphite cast iron

The range of relevant cutting parameters like cutting speed, depth of cut, and feed for different cutting tool materials and special cast iron alloys are given in Table 4.

Table 3.General recommendations for turning operation of cast iron alloys and Properties of highly developed cutting tool materials and coatings [20].

Workpiece material	Cutting tool material	Properties of advanced cutting tool materials and coatings				
		Microhardness (HV)	Coefficient of friction against steel in dry contact	Maximum working temperature (^{0}C)	Thermal conductivity (W/m K)	Transverse rupture strength (MPa)
cast iron alloys	PCD	6000	-	600	500	690-965
	CBN	3500	0.24		100	690
	WC	1500-1800	0.6		40-80	1700-2000
	SiN	1700		-	15-35	480-750
	Al O	1600	-		14-17	275-345
	Coated material					
	TiN	2900	0.4	600	-	-
	TiCN	3000	0.4	400	-	-
	TiAlN	3300	0.3-0.5	815	-	-

Examined the weight of the cutting parameters on the cutting force when machining gray cast iron (HBW242) with a coated carbide tool (AC410K). It was found that the cutting forces decrease when mounting cutting speed and decreasing depth of cut. The optimal cutting parameters were recognized when cutting speed was varied from 45 to 55 m/min, depth of cut from 0.5 to 1.5 mm, and feed from 0.1 to 0.2 mm/rev [13].

Table 4. General recommendations for turning operation of cast iron alloys and The range of applicable cutting speeds, depth of cuts and feeds for a variety of tool materials[13].

Workpiece material	**Cutting tool material**	**General-purpose starting conditions**		
		Depth of cut in mm	Feed mm/rev	Rotational speed rev/min
cast iron alloys	Uncoated carbide			250-750
	Polycrystalline carbide			400-800
	The range for roughing and finishing			
		Depth of cut in mm	Feed mm/rev	Rotational speed rev/min
	Uncoated carbide			150-350
	Ceramic-coated carbide	0.5-1.5 mm	0.3-0.7 mm/rev	45-55 m/min

In the machining of cast iron, ceramic-coated carbides are the most commonly used tools. In the present study, selected ceramic-coated carbides grades and coated carbides were investigated. Using ceramic-coated carbides tools instead of uncoated ceramic carbides tools increases yield in terms of cutting speed by 25% while tooling life increases [13],[42].

2.4. Factors Affecting Surface Finishing

Machinability commonly is definite in terms of surface finish, tool life, force and power supplies, and chip management. The machinability of materials depends on their masterpiece, properties, and microstructure. Thus, proper selection and control of process variables are key. Many investigations have been done so far to specify the correlation between turning circumstances and their influences on the machining result. Optimization of machining processes is usually based on ruling operating conditions, which play down machining costs or get the most out of the production rate. The three chief process parameters in this research are depth of cut, cutting speed, and feed. The surface roughness of a turned workpiece is needy on these process parameters and also on tool geometry (nose radius, rake angle, side cutting edge angle, and cutting edge). In addition, it also depends on the several other exogenous factors such as workpiece material and tool material type and their mechanical properties, quality and type of the machine tool used, auxiliary tooling, and lubricant used, and vibrations among the workpiece, machine tool, and cutting tool[1], [21-25],[49]. Therefore, related literature with these parameters has been discussed as follows in different sections.

2.4.1 Material Type

The type of material to be machined plays a vital role to get the yield with a high surface finish. It helps to select the correct cutting parameters and recommended cutting tool for turning operation and the potency of material to be machined is less than that of the cutting tool. This is another way it makes the right machining operation as the process of the final product was achieved the required dimension and accuracy. The influence of material elastic recovery on-chip breadth and surface generation in Ultra Precision raster milling was studied in [23]. The experimental results showed that the wished-for surface roughness forecast model makes a more precise prediction by adding the elastic recovery rate as a material factor and the presence of elastic recovery improves the surface finishing of the raster milled surface. Material property is a particular value in the machining process. It makes a great contribution to surface roughness formation in Ultra-precision machining due to the “size effect” were studied [24]. Considerable research concern has been attracted in studying the effect of material properties, such as material isotropy and anisotropy and material homogeny and non-uniformity on surface roughness. For different isotropic materials, the machined surface roughness under the same cutting conditions is diverse.

2.4.2 Type of Cutting-Tool Material

The choice of cutting-tool materials for a particular relevance is among the most important factors in machining operations. The type of tool material affects surface roughness and surface integrity of machined yield during the turning process. The strength of the cutting tool must be elevated than that of the material to be machined. The selection of the right tool materials depends not only on the material to be machined but also on process parameters and the distinctiveness of the machine tool. Generally, there are many types of cutting tools used for turning operation, some of them are high-speed steel (HSS), non-coated brazed type carbide tool, coated carbide tool, ceramic tool, and cubic boron nitride (CBN) tool. The cutting tool separates chips from the workpiece to hold the desired shape and size. There are a vast variety of metal cutting tools, each of which is considered to perform a particular job. A single-point cutting tool is used to turn a variety of cylindrical shapes on a lathe machine[46]. To eliminate chips from the workpiece the following condition must be satisfied.

- The cutting tool must be harder than the metal to be cut.
- The cutting tool must be shaped cutting edge which can penetrate the workpiece
- The tool should be tough and rigid enough to oppose cutting forces and
- There must be a virtual rotation of the spindle with a workpiece and longitudinal motion of the cutting tool as the workpiece to make the cutting process correctly.

The cutting tool is subjected to high temperatures, high contact stresses, and friction along with the tool–chip interface and along the machined surface. Therefore, the cutting-tool material must acquire the following characteristics to resist the tool wear that happened during the turning process: hot stiffness, thermal shock resistance, wear resistance, toughness and impact strength, and chemical stability and inertness concerning the material being machined, to avoid or minimize any undesirable reactions, adhesion, and tool–chip diffusion that would give to tool wear[46]. The use of ceramic (alumina and sialon) tools for machining cast iron has increased greatly in recent years, mainly in mass fabrication turning, boring and milling operations. Most cast-iron brake drums, clutch faces, and flywheels are today, being machined with ceramic tools. The excellent surface finish achieved often eliminates the need for a grinding operation. Because the chips are fragmented, very high cutting speeds can be used without problems with chip control.

2.4.3. 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 essential parameters in the turning process and it is the speed of the workpiece surface relative to the edge of the cutting tool during a cutting progression, measured in surface meter per minute. The rotating speed in turning is related to the preferred cutting speed at the surface of the cylindrical workpiece during the process.

$$V_C = \frac{\pi D N}{1000} \tag{2.10}$$

Where, Vc-cutting speed in m/min,

N - Spindle speed in rev/min and

D- Outer diameter in mm.

Feed rate is the rate at which the tool advances into the work. The feed-in spinning 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;

$$f_r = Nf \tag{2.11}$$

Where, f_r- feed rate in mm/m,

N- Spindle speed in rev/min and

f- feed in mm/rev

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

$$d = \frac{D_0 - D\text{i}}{2} \tag{2.12}$$

Where, d-depth of cut in mm,

Do-outer diameter in mm, Di-final diameter in mm

Surface roughness is highly precious by cutting parameters like cutting speed, depth of cut, and feed rate during turning route on conventional lathe machine. These parameters must be within the recommended range depending on the type of material to be machined, tool geometry, and tool material. A researcher in[26]optimized CNC lathe machine turning process Parameters for a guess of surface Roughness through Taguchi's parametric Design approach. Their outcome shows that the influence of surface roughness (Ra) is dependent on feed and next is followed by speed and depth of cut. And another researcher in[27] has studied Parametric Analysis and optimized the effect of cutting speed, feed rate, time, and depth of cut on the surface final of high stainless-steel material in turning process by Taguchi approach. The optimization of cutting parameters in wet turning of EN24 steel and Taguchi method were studied in [28]. Their consequence shows that feed rate followed by the depth of cut and spindle speed was the combination of the optimal levels of the factor. Machining parameters in turning operation using Taguchi exploration are optimized by researchers in[14]. They studied the effect of speed, feed, and depth of cut on material removal rate, surface roughness and tool wear in machining AISI 4320 alloy steel using a tungsten carbide tipped cutter. The results point to that the cutting speed is the leading issue moving all three investigation parameters. The effect of spindle speed, feed rate, depth of cut on surface roughness of aluminum samples in end milling was studied [29]. And the study shows that cutting feed is by far the foremost factor of those studied. The upshot of feed rate, depth of cut, and lubricant temperature on the plain roughness of steel by using the Taguchi method was willful in[2]. And the result showed that a better surface finish is obtained at cooling lubricant. proportional study on optimization of surface roughness Parameters in turning EN1A steel on a CNC lathe with Coolant and without coolant was studied by a researcher in [30]. His result shows that the best surface finish has occurred with the coolant used. Another person in[31]studied the authority of spindle speed, feed rate, and depth of cut on the surface roughness of Al-7075 alloy during end milling and the result showed that spindle speed and feed rate are the most major factors affecting the surface finishing during the procedure. The surface roughness of the unalloyed specimen is significantly higher (Ra 2.97 µm) than those of the alloyed specimens of cast iron. This can be explained by exploratory the microstructure and mechanical properties of this specimen. noticeably higher ferrite content (87.72%) of this specimen is thought to affect cutting forces positively. That is because high ferrite content in this specimen led to a lower cutting force requirement than the alloyed specimens which hold high amount of pearlite in their structures. Lower tensile strength (498 MPa) and lower hardness (9.2 HRc) of this specimen are other reasons for the lowest force recorded when turning in [32].Finally among machinability criteria, only cutting forces and surface roughness were investigated.

2.4.4 Tool Geometry

A cutting tool must own a shape that is well-matched to the machining operation. One important way to classify cutting tools is according to the machining process. Thus, there are dissimilar types of tools for different operations like whirling tools, cutoff tools, milling cutters, drill bits, reamers, taps, and many other cutting tools that are named for the operation in which they are used, each with its tool geometry in some cases quite dissimilar [19]. The cutting part of a turning tool comprises the rake face and the major and minor flank faces. The comparative direction of these surfaces to one another determines the tool angles. The choice of cutting angles has a most essential outcome on the results of a machining operation and the tool life. The greater the weight on achieving cost-effective material processing and the importance of formative optimal tool geometry. Therefore, the stability and life of the cutting tool can be raised by selecting correct cutting angles and using chamfered and rounded cutting edges[37]. Single point cutting tool is used for turning procedure in which, the orientation of the rake face is defined by two angles back rake angle(α_b)and side rake angle(α_s) and these angles are influential informative the direction of chip flow across the rake face. The flank surface of the tool is defined by the end relief angle(ERA) and side relief angle(SRA) which is used to conclude the amount of clearance between the tool and the newly cutwork surface. The cutting edge of a single point tool is separated into two sections, side cutting edge, and end cutting edge. They are separated by the tool point, which has a certain radius called the nose radius. The side cutting edge angle (SCEA) determines the way inside tool into work and can be used to reduce the unexpected force tool experiences as it enters a work part. Nose radius (NR) determines to a large degree the texture of the surface generated in the operation. End cutting edge angle(ECEA) provides a clearance between the trailing edge of the tool and the newly generated work surface, thus reducing rubbing and friction against the surface[1], [17],. Generally, there are seven elements of tool geometry for a single-point tool which, are jointly called the tool geometry mark; back rake angle, side rake angle, end relief angle, side relief angle, end cutting edge angle, side cutting edge angle, and nose radius. For example, a single-point tool used in turn may have the following signature: -6, -6, 7, 7, 20, 15, 2/64 in degree [33].

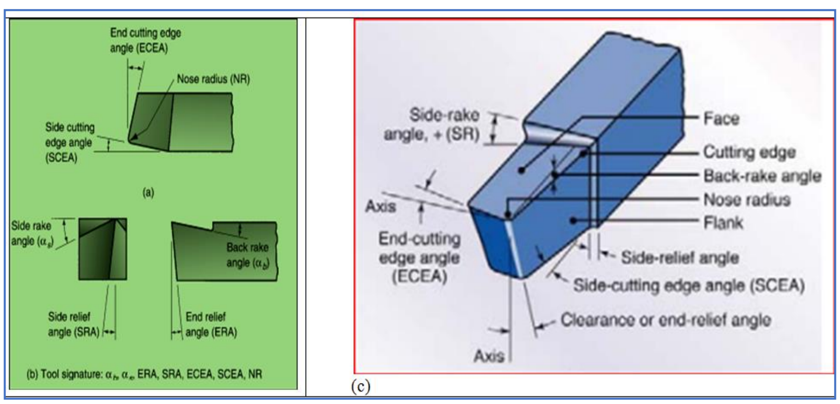

Figure 7. (a) Seven elements of single-point tool geometry 2D, and (b) the tool signature convention defines seven elements (c) elements of single point cutting tool geometry 3D[34].

The consequence of side rake angle, back rake angle, feed, spindle speed, and depth of cut on the surface roughness of mild steel and the result showed that supply is the most huge parameter influencing surface roughness and side rake angle is having very less effect on surface roughness of mild steel by using ANOVA method were studied [35]. A researcher in [36]studied the effects of the tool cutting edge geometry and workpiece hardness on the surface roughness and cutting forces in the come to an end hard turning of AISI 52100 steel. And finally, the study showed that the cutting-edge geometry has a significant effect on the axial and radial cutting force mechanism and also on the surface roughness. Failure system and factors affecting the micro end mill during machining of cast iron workpiece. The machining process was performed at various cutting speeds, feed rates, and depth of cuts to identify failure mechanisms using two different helix angles. Chips observed were fragmented in shape based on the cutter geometry. The effect of depth of cut was reported as an increase in depth of cut increases tool life [37]. An experimental investigation was conducted to determine the effects of tool cutting-edge geometry and workpiece hardness on surface residual stresses for finish hard turning of through-hardened AISI 52100 steel[37]. This study shows that tool edge geometry is highly influential with value to surface residual stresses, which are measured using x-ray diffraction.

2.4.5 Machine Stability

It affects the surface roughness of finished manufactured goods as the stability of the machine was changed. It includes the vibrations and, motional accurateness of the workpiece, tool, and machining utensils. In the turning operation shaking is a frequent problem, which affects the result of the machining and mainly the surface finish. Tool life is also partial by vibration. harsh sound noise in the working environment often occurs as an outcome of dynamic motion between the cutting tool and the workpiece. Tool vibration is a dynamic shakiness of the cutting process, which is a result of the crossing point between the metal cutting process and the dynamics of a machine tool. The occurrence of such tool vibration leads to a poor surface finish, which results in cutting tool breaks and the production of irritating and improper noise. To reduce tool pulsation, a magnetorheological fluid damper was developed in [38], that will respond to an applied field with a dramatic change in their rheological behavior. In their studies, a Mathematical mock-up was engineering, and amplitudes of the tool vibration and chip thickness were calculated. A correlation between surface roughness and cutting tool vibration in turning operation by taking different levels of process parameters like speed, depth of cut, feed rate, and tool overhanging were studied by researchers in[39]. Their result shows that the best surface roughness condition is achieved at a low feed rate and smaller tool projection. The relations between tool overhang and vibration signal features are investigated by another researcher in[40]. Based on their study, it can be completed that tangentially shaking signal features are highly affected by overhang length. The effects of changes in the tool overhang in the external turning process on both the surface quality of the workpiece and tool wear were investigated in[34]. Their result shows that the surface roughness of workpiece increases as the tool overhang increases and Using the same tool overhang, the surface roughness of the work piece increases as the depth of cut increases.

2.5. Research Motivation

In many manufacturing industries, the surface quality of the machined product plays a vital role to increase the customer's demand and the competitiveness between the manufacturers. Without surface quality, it is difficult to talk about the high production rate, long life of the product without imperfection, crack formation, and corrosion resistance. And also surface quality plays a vital role in the applications of meeting parts in which various parts are used. Thus, the inspiration for this work is mainly due to the above reasons.

2.6. Statement of the problem

In the metal manufacturing industries machining is still the most commonly used method of product formation. Better quality at lower cost in a minimum time is increasing the competitive nature among the manufacturers. The result of optimum parameters in the machining process is very important due to challenges in machining. Nowadays, especially in terms of surface quality and cost of machining, care should be taken. Turning is the most common machining process obtainable to meet the needs like dimensional accurateness, surface finish, and no involvedness machining of material. Surface roughness remains the main indicator of machined section quality as it is related to surface quality. In turn, higher values of cutting parameter on hand opportunities for increasing productivity but it also involves greater risk of descent in surface quality and tool life if there are improper process parameters were used. In the turning operation, cutting parameters are the most common factors which affect the result of machining particularly the surface finish of the product. Flake graphite cast irons are considered to have extremely machining behavior. A major reason for the nonstop large-scale use of cast iron in engineering is not only the low cost of the material and the casting process but also the economics of machining the finished element. By nearly all criteria cast iron has good machinability: low charge of tool wear, the high duty of metal removal, relatively low tool forces, and low power utilization. The surface of the machined cast iron is rather difficult to finish well in character, but best for many sliding interfaces. The chips are produced as very small waste. There is a great difference between the behavior of cast iron when sheared. The most difficult distinguishing is that fracture on the shear plane occurs at very frequent intervals, initiated by the graphite flakes. The chip is thus self-possessed of very small remains a few millimeters in length. Because the chips are not continuous, the length of contact on the rake face is very short. The chips are thin and the cutting force and power utilization are low. The cutting force is low also because graphite flakes are very weak. For turning gray cast irons these are classified according to rigidity when using the three classes of tool material. The use of ceramic (alumina and sialon) tools for machining castiron has increased seriously in recent years, mainly in mass invention turning, boring and milling operations. Most cast-iron brake drums, clutch faces, and flywheels are today, being machined with ceramic tools. To minimize the failures of materials due to properties like corrosion, wear and fatigue it is important to investigate and optimize the cutting parameters that affect the surface roughness of Flake graphite cast iron in turning operation. The excellent surface finish that had been achieved often eliminates the need for cutting fluid, using the dry cutting operation to reduce the cutting force that appears due to cutting fluid. Because using dry cutting operation chips were fragmented and stir up ductility due to temperature increase during dry machining operation, very high cutting speeds were used without problems of chip control. There is less work done on optimization of dry turning parameters for dry machining of flake graphite cast iron was not studied in detail. Therefore, studying the effect of machining parameters on the surface finish of dry turning flake graphite cast iron and determining the optimum parameters and less machining force of dry turning is the intention of this work.

2.7. Research Question

The following research questions are raised from the above portion.

1. What are the optimum cutting conditions to machining particularly flake graphite cast iron and most significant catting parameters?
2. During machining flake graphite cast iron in dry turning on conventional lathe machine what difficulties may appear? How can tolerate them?

3. What cutting parameter can give expressed material removal rate, productivity, and quality?
4. What does the chip morphology of flake graphite cast iron look like?
5. How long is the tool life and how much is it wear?

2.8. Objectives

2.8.1. General objectives

The general objective of this research is to study dry turning Flake graphite cast iron surface finishing on conventional machining (turning) and optimization of cutting parameters.

2.8.2 Specific objectives

The specific objectives of the research are listed below.

1. Studying optimum cutting parameters which give better surface finish in dry turning of Flake graphite cast iron.
2. To determine the material removal rate for productivity at optimized parameters.
3. Investigation of the behavior of tool wears using qualitative measurement analysis.

2.9. Significance of the studies

study the machining parameters that affect the surface quality of cast iron is very important to manufacture products with better surface finish. Turning is the most common type of conventional machining progression. It is important to study the effect of cutting parameters. Generally, the significances of this study are to optimize the cutting parameters, obtain a better surface finish. Dry turning on conventional lathe machines is applicable in terms of the cost of equipment as well as the cost of the machining process. It is the best processing technique as compared to turning using cutting fluids, high material removal rate, these special properties make it attractive to Most flake graphite cast iron brake drums, clutch faces and flywheels are, today and another traditional machining process.

2.10. Scope and limitations of the study

The study is highly focused on the mechanism of the turning process, on the optimization of tuning parameters, identifying the most process parameters that affect the surface quality of Flake graphite cast iron materials, and how we improve the surface quality of products in the manufacturing process to make the most of revenue, production rate, to increase tool life and to increase the customers demand. In this paper, the effect of cutting parameters on the surface roughness of machined products of Flake graphite cast iron material was studied. But due to the luck of dynamometer testing of cutting force and machine vibration did not conduct.

CHAPTER THREE

MATERIALS AND METHODOLOGIES

3.1 Introduction

This study was performed to investigate the machining parameters which affect the surface roughness in turning operation of flake graphite cast iron which is commonly used in most cast-iron brake drums, clutch faces and flywheels are, today, being machined with the ceramic cutting tool through trial investigation. This section aims to present the details of the experimental events and material used for the study. All machines and instruments were discussed with supporting photographs and schematic diagrams.

Table 5.Chemical composition of flake graphite cast iron (w%).

Element	C	Si	Mn	P	S	Cu	Cr	Fe
Content	3.40	1.94	0.61	0.02	0.09	0.63	0.21	Balance

Experimental Procedure

The overall stage of experimental studies of optimization parameters in turning process flake graphite cast iron is shown in Figure 8.

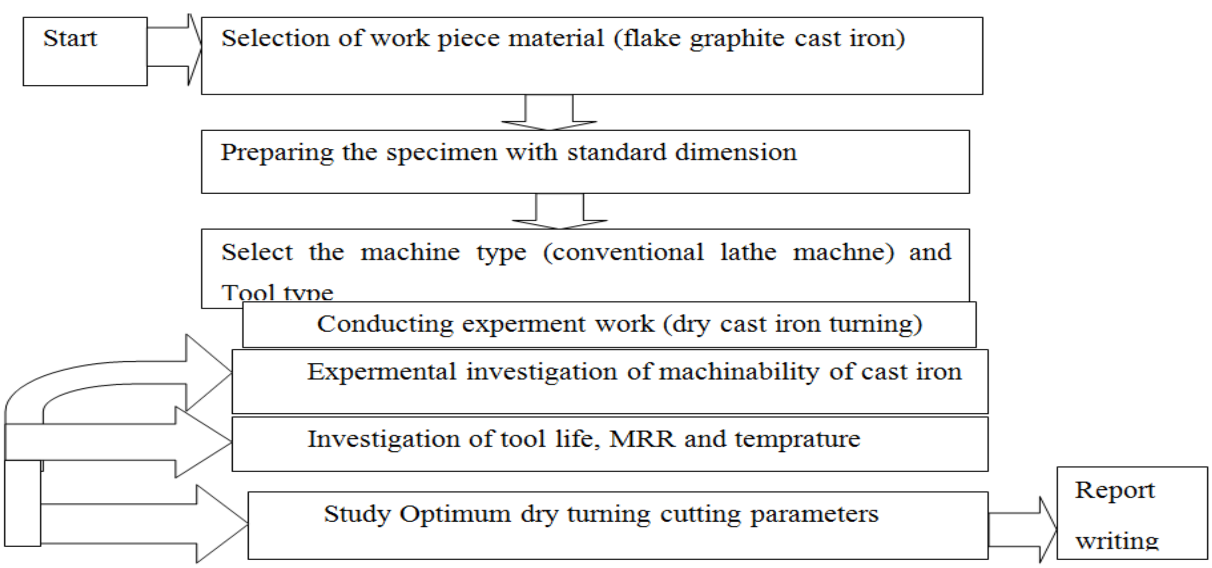

Figure 8.Experimental Procedure/project flow chart

3.3 Materials

Materials used for this study was flake graphite cast iron which is widely used in the most cast-iron application of brake drums, clutch faces, and flywheels. The excellent surface finish achieved often eliminates the need for grinding action. Because the chips are fragmented, very high cutting speeds are optimized without problems of chip control, etc. The cylindrical shape workpieces use to perform the experiments have a length of 300 mm and a diameter of 30mm of flake graphite cast iron.

3.3.1.Properties of workpiece material

Flake graphite cast irons are well-thought-out to have very fine machining behavior. A major explanation for the nonstop significant use of cast iron in engineering is not only the low cost of the material and the casting progression but also the economics of machining the finished section. By nearly all criteria cast iron has good machinability: low tariff of tool wear, high rates of metal removal, relatively low tool forces, and low power utilization. The surface of the machined cast iron is rather not shiny, but best for many sliding interfaces. The chips are twisted as very small remains which can voluntarily be cleared from the cutting area even when machining at elevated speeds [48].

3.3.2 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).

3.3.3. Equipment Used

A conventional engine lathe machine was used for experimental study for the turning process of cast iron alloy material. Most cast iron used in different applications like brake drums, clutch faces, and flywheels is today, being machined with ceramic tools. The lathe machine with the model of PSG A141 and power 7KW with a spindle speed range of 15rpm to 2000rpm was used for this study. A general view of a conventional lathe machine with its main components is shown in Figure 9. Generally, the equipment used for the study is;

Optical microscopy,

Lathe machine with model PSG A141

Profilometer

Micro meter

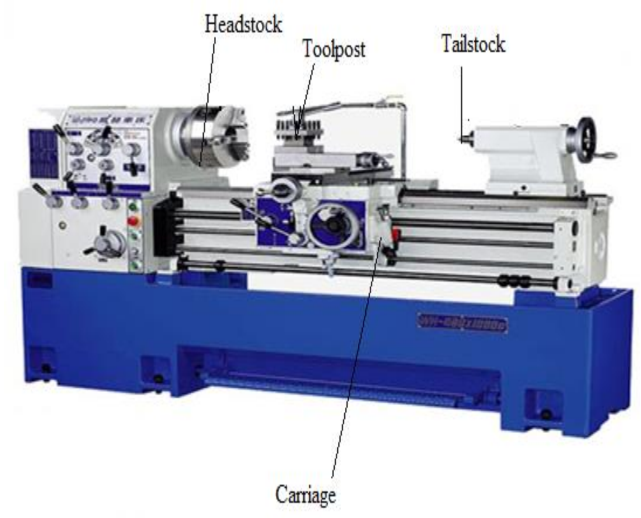

Figure 9. General view of a typical lathe, showing various components

3.4 Research Methodology

By using the materials mentioned above from side to side following method the experimental work would be continued. Under research methodology the way of specimen preparation, design of experimentation procedure, selection of orthogonal array, analysis of variance, methods for measuring surface roughness using different soft ware.

3.4.1 Specimen Preparation for Turning Operation

The workpiece materials used for this study were a common alloy of cast iron circular rod of 300 x 31 (Length x Diameter) mm used for turning on conventional lathe machine by turning to remove impurities of 1 mm as well as facing length to 290 mm. The experiment was conducted on the conventional lathe machine with different combinations of turning process parameters. The surface roughness values for all the experiments for turning operations were calculated. ANOVA is used to recognize the major factors disturbing the surface roughness. Experiments with a length of 30mm and 0.5, 1.0, and 1.5mm of the depth of cut would be operated with dissimilar turning parameters for experimental study with different cutting parameters which are selected by using an orthogonal array.

3.4.2. Design of Experiment

In the design of experiment (DOE), the Taguchi method is commonly used because it is a problem–solving tool which can improve the performance of the product, process design, and system. The design of an experiment is a technique of defining and investigating all possible conditions involving various factors, parameters, and variables in an experiment. To monitor the most influential process parameters in the turning process namely cutting speed, feed, and depth of cut each at three levels was well-thought-out in the case of this thesis. The Taguchi design procedure is shown in Figure 10. and the selected process parameters, levels, and their values at different levels are given in Table 6.

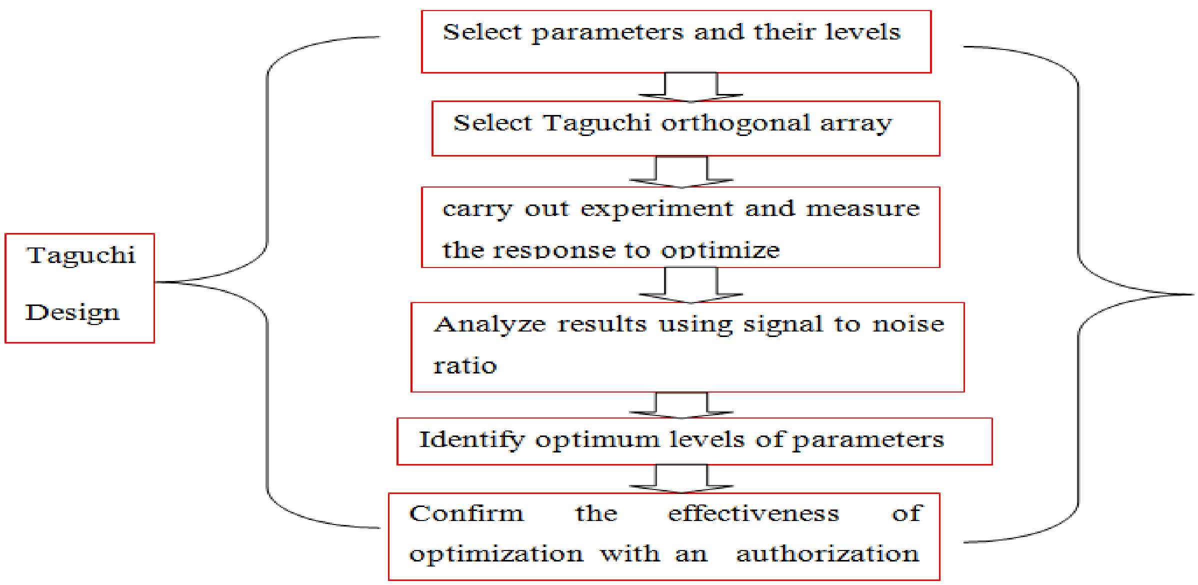

Figure 10 .selected process parameters, levels, and their standards at different levels

Taguchi uses the S/N ratio to measure the quality characteristics deviating from the preferred value and it offers three categories of signal to noise ratio as follows;

The larger the better is fitting for determining the profit, production rate, etc.

The Nominal the better is appropriate for current.

The smaller the better is appropriate for surface roughness, tool wear, unit cost, etc.

Cutting parameters for cast iron were selected depending on the suggested cutting parameters which are given in Table 6. and the range was taken to get the accurate outcome since the maximum difference was at maximum range.

Table 6.List of parameters and their levels.

Cutting parameters	Parameters designation	Level		
		1	2	3
Cutting speed (m/min)	A	45	50	55
Feed (mm/rev)	B	0.3	0.5	0.7
Depth of cut (mm)	C	0.5	1.0	1.5

3.4.3 Selection of Orthogonal Array and Column Assignment

The cutting experiments were carried out on a conventional lathe machine by using ceramic coated carbide tools for machining of flake graphite cast iron workpiece with selected cutting parameters within three levels given in Table 6. according to suggested cutting parameters for cast iron alloys. The selection of an exacting orthogonal array was based on the number of levels of various factors. Here, to conduct the experiments 3 factors each at 3 levels were selected. Now the Degree of Freedom (DOF) can be calculated by the formula as given below.

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

Where, DOF= degree of freedom,

P = number of factors and

L = number of levels

$$DOF = 3 * (3 - 1) \approx L_9 \qquad (3.2)$$

However, the total number of experiments of the orthogonal array (OA) should be larger than or equal to the total DOF required for the testing. Thus, the L_9 orthogonal array was preferred to make the supplementary experiments are shown in Table 7.

Table 7.Experimental Layout Using an L-9 Orthogonal Array.

Ex. no	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
01	45	0.3	0.5
02	45	0.5	1
03	45	0.7	1.5
04	50	0.3	1
05	50	0.5	1.5
06	50	0.7	0.5
07	55	0.3	1.5
08	55	0.5	0.5
09	55	0.7	1

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

$$SN = -10log\left[\frac{1}{r}\sum_{i=1}^{1}(y_i)^2\right] \tag{3.3}$$

Here y = observation, r = total number of observations and y_i = i^th^ response. The S/N ratio was calculated for surface roughness in each of the nine trial situations to see the end product of each parameter on the answer.

3.4.4 Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) was to find which parameters significantly affect the superiority 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 aspect were used to measure the corresponding effects on the performance distinctiveness. The significance level of 5 %, i.e. for 95 % level of confidence was well-thought-out in this analysis. ANOVA results indicate whether there is statistical significance in disparity or not in output characteristics. ANOVA analysis involves when α values are below 0.05 is significant and above 0.05 is not significant. Percent input measures the percentage involvement of each model term relative to the total sum of squares. The percentage contribution is regularly a rough but effective guide to the relative value of each model term. From the analysis of variance Percentage contribution of each influential parameter was calculated by the following formula:

$$P(\%) = \left(\frac{SSTR}{SST}\right) * 100 \tag{3.4}$$

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.

3.4.5.Studying Surface Roughness

The quality of the surface made using conventional and non-conventional machining is important because a smooth surface reduces the chances of surface scratches caused by wear and corrosion. Likewise, the superiority of a part made by turning operation can affect the performance of the surface for wear and corrosion safeguard. The surface profiles of all samples were quantitively analyzed to determine the statistical standard parameter of average roughness, R_a by using mark surface. The roughness of a surface cannot be easily clear by a single parameter. It's a basic property of the surface and every test condition was repeated at least three times at different new locations on a rod bar surface to make certain the repeatability and reproducibility of the result. In this study, after the turning process of flake graphite cast iron with different cutting parameters, the centerline average surface roughness was measured by a surface contact profilometer

Figure 11.surface contact profilometer

3.4.6 Analysis of 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 capacity from the initial and final weight of the job. For each revolution of the workpiece, a discontinuous fragment of material is removed which has a cross-sectional area that equals the product of expanse, 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 chip is the product of the cross-sectional area (f) (d) and the average circumference of the ring $\pi D_{avg,}$ as narrated in equation 2.1,2.2,2.3 and 2.4 above.The rotational speed of the workpiece is N and the material removal rate per Revolution is $\pi \mathrm{D}_{\mathrm{avg}}(f)(d)$ since there are N revolutions per minute and the removal rate is given by:$MRR = dfV$. The cutting time t, for a workpiece of length l can be calculated by noting that the tool Travels at a feed rate of $fN = \left(\frac{mm}{rev}\right)\left(\frac{rev}{min}\right) = \frac{mm}{min}$ since the distance traveled is $l$mm. The cutting time can be given by equation (2.4): $t = \frac{l}{fN}$, Cutting force is a key performance parameter in which directly affects the turning process. Some factors like tool breakage, tool wear, and workpiece deflection are mainly developed

due to cutting force fashioned during the machining process.

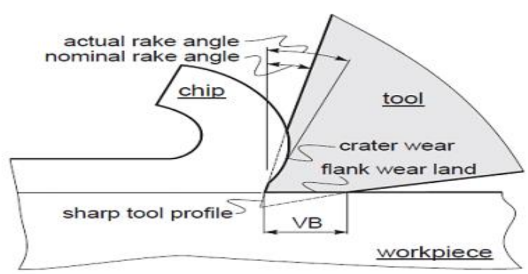

Figure 12. shearing operation during material removal.

3.4.7. Measurement of Tooltip Temperature

Metal cutting is a complicated process. When the metal cutting process starts then plastic buckle occurs and wrought heat between chief share zones. It could be understood that all the required cutting energy is transformed to heat. The making of the heat during machining increases the temperature in the cutting zone which affects the strength, hardness, wear-resistance, and tool life of the cutting tool and causes involvedness in scheming the dimensional accuracy and surface integrity. The findings of some of the research studies about the effect of cutting parameters on heat creation and cutting temperature. In the case of flake graphite cast iron higher amount of graphite lowers the material strength which is directed to non-linear deformation behavior and has a less average temperature. It has less stress load on the tool during machining, tool life increased, and has moderate cutting force. An analytical prediction model for the measurements of cutting temperature during machining was concluded that the cutting temperature is the function of cutting speed and feed rate [15][38].

$$\boldsymbol{\theta t} = V \times 0.5 \times T \tag{3.5}$$

Where, θt = Average cutting temperature

V = Cutting speed ,

T = Underformed chip – thickness

3.4.8.Studying 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 the chip formation process can be most readily seen using the orthogonal cutting representation. In the orthogonal model, chip formation is considered to occur as a two-dimensional process in a plane perpendicular to the cutting edge [41]. 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 distorted 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, the main type of chip that can be formed is fragmented chips. The chips are formed as very small rubbish which can voluntarily be cleared from the cutting area even when machining at very far above the ground speeds. It is to some amount dirty and sandy action, throw a fine scatter of graphite into the air, so that fortification for factory employees may be necessary. Like when cutting other supplies, there is a great differentiation between the behavior of cast iron when sheared on the shear plane and at the tool work interface. The most significant feature is that come apart on the shear plane occurs at very common intervals, initiated by the graphite flakes. The chip is thus composed of very small remains a few millimeters in the piece. Because the chips are not continuous, the length of make contact with the rake face is very short. The chips are skinny and the cutting force and power utilization are near to the ground. The cutting force is low also because graphite flakes are very weak. One flake may lengthen a significant way across the shear plane.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

An experimental study was conducted to evaluate the consequence of cutting parameters namely cutting speed, depth of cut, and feed on the surface superiority of cast iron during the turning process. The results for each experiment were discussed in this chapter. The design of the experiment was used to identify the optimum cutting parameters and to identify the most influential parameters.

4.2 Samples After Turning Process

All nine experiment’s with dissimilar cutting parameters but with the same length of 31mm after the dry turning process of cutting cast iron material are given in Figure 4. The diameter of the workpiece prepared for experimental work is 27mm and after the turning process, it's reduced with 0.5, 1, and 1.5mm depth of cut. Experiment numbers 1, 2, and 3 were operated by a similar cutting speed of 45m/min but, with different feed (0.3, 0.5, and 0.7 respectively) and depth of cut 0.5, 1, and 1.5 respectively). In a similar manner experiment numbers 4, 5, and 6 were operated by a similar cutting speed of 50m/min but with different feed (0.3, 0.5, and 0.7 respectively) and depth of cut (1, 1.5, and 0.5 respectively). And the last three experiments were also operated by a similar cutting speed of 55m/min, but with different feed (0.3, 0.5, and 0.7 respectively) and depth of cut (1.5, 1and 0.5 respectively).

Figure 13. Samples after turning process.

4.3 Optimization of Process Parameters on The Surface Quality of flake graphite cast iron

As the intention of this study was the optimization of tuning parameters for flake graphite cast iron using the Taguchi method, through the Taguchi course of action the optimum turning parameters and the most significant factors that affect the surface quality of the machined product would be identified as follows.

4.3.1 Taguchi Design of Experiment

Taguchi's orthogonal arrays are highly fractional orthogonal designs. Orthogonal array designs focus chiefly on main belongings. These designs can be used to approximation main effects using only a few experimental runs. Taguchi Signal-to-Noise ratios (S/N), which are log functions of the desired output, supply as objective functions for optimization, help in data analysis, and forecast of optimum fallout. In the Taguchi method, comeback variation is studied with the help of the signal-to-noise (S/N) ratio. The uncontrollable parameters have affected the quality of the characteristics. The undesirable parameter values are expressed as "noise" (standard deviation) and advantageous parameters values are termed as "signal (mean). Under the investigation, the product quality strong-minded factors, which are assigned in the design of the experiment elevated as response factors of the analysis. The external uncontrollable factors, outcome quality of the product are affected. Specimens are prepared based on the L_9 orthogonal array and the S/N ratios are calculated using MINITAB 18 software. The SN ratio for “smaller is better” is used to identify the optimum parameters because a smaller surface roughness is most wanted in this study.

4.3.2 Analysis of Mean for Surface Roughness Test

The average mean value of surface roughness for each cause i.e. Cutting speed (A), feed (B), and Depth of cut(C) considered using the design of experiments. Table 4. presents the experimental outcome of surface roughness (Ra) values for each sample and their mean values. In this study, each surface roughness (Ra) trial value is the middling of three trial readings.

Table 8.Experimental result for the mean value of surface roughness.

Experiment No.	Cutting speed m/min)	Feed (mm/rev)	Depth of cut (mm)	Surface roughness (μm)			Avg. Ra (μm)	S/N ratios
				Trial 1	Trial 2	Trial 3		
1	45	0.3	0.5	2.63	2.31	3.18	2.71	-8.659
2	45	0.5	1	2.40	3.69	4.18	3.42	-10.680
3	45	0.7	1.5	3.16	3.63	3.71	3.50	-10.881
4	50	0.3	1	2.50	1.99	1.89	2.13	-6.567
5	50	0.5	1.5	2.73	2.77	2.33	2.61	-8.332
6	50	0.7	0.5	2.86	2.95	2.12	2.64	-8.432
7	55	0.3	1.5	1.76	2.39	1.87	1.97	-5.889
8	55	0.5	0.5	2.47	2.23	2.01	2.24	-7.004
9	55	0.7	1	2.45	2.29	2.37	2.37	-7.494
Average performance mean value							2.62	-8.326

The mean value of surface roughness for each factor i.e. Cutting speed (A), Feed (B), and Depth of cut (C)at each level are obtained and the result is listed in response Table 9.

Example calculation is shown for factor A (Cutting speed):

$$S/N_{A1} = \frac{2.71+3.42+3.50}{3} = 3.21$$

$$S/N_{A2} = \frac{2.13+2.61+2.64}{3} = 2.46$$

$$S/N_{A3} = \frac{1.97+2.24+2.37}{3} = 2.19$$

Table 9.Response table for mean effects plot for smaller is better.

Level	Cutting speed	Feed	Depth of cut
	Symbol		
	A	B	C
1	3.21	2.37	2.60
2	2.46	2.76	2.64
3	2.19	2.84	2.69
Delta	1.02	0.47	0.09
Rank	1	2	3

The control factors' main effect plot for means of surface roughness value variations is as shown in Table 4.1. The result taken from the above data shows means as smaller is better is selected for surface roughness value output.

Delta=(Maximum mean-Minimum mean)

The factor with the greatest effect on the mean from Table 9. is cutting speed (Delta = 1.02, Rank = 1). The factor with the least effect on the mean is the depth of cut (Delta = 0.09, Rank = 3). Since main effect plots for means helps adjust the mean on better value. Those parameter levels with better surface finish value of specimens that means **A3B1C1** taken as a possible parameter combination for better values significant factors in the order increasing by touching surface roughness is the depth of cut, feed and cutting speed as its seen on Table 9. As observed from figure 14. that within the scope of this investigation the minimum point in the graph for each turning parameter is the optimum conditions. The minimum point for cutting speed is at level three which is indicated to 55m/min speed, the minimum point of feed indicated at 0.3 on the figure and for a depth of cut is at level one of 0.5mm.

This is due to the identified optimum turning parameter was at high cutting speed, medium feed, and low depth of cut which is A3B1C1.

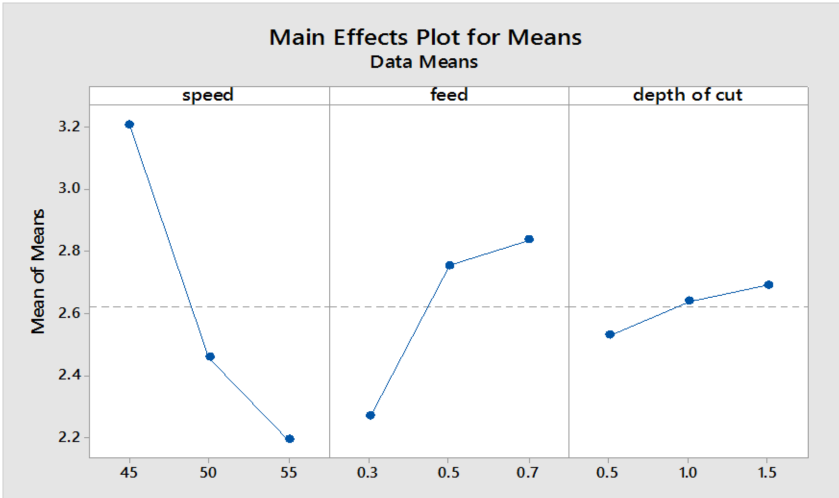

Figure 14. Main effect plot means.

It can be seen from Figure 14. that within the range of this examination the lowest point in

the graph for each turning parameter is the optimum circumstances. The minimum point for cutting speed at level three, but for feed and depth of cut minimum point on this graph was at level one for each level. As presented in [43] high cutting speed does not only decrease machining price by mounting production quantity and charge but also consequences in good plane excellence of machined parts. This is why the identified optimum turning parameter was at high cutting speed, intermediate feed, and low depth of cut which is A3B1C1. The figure below shows the effect of feed and depth of cut on surface roughness (Ra) at cutting speeds of 45,50, and 55m/min by using Origin8 software spline graph. Note: - In the figure, the average surface roughness (y) and the depth of cut or feed (x) are represented by the spline graph. The result is shown by the graph for the effects. As feed value, 0.7 mm/rev at speed 45m/min the surface roughness value is 3.5 µm and at 0.5 mm/rev, the surface roughness was decreased to 3.42 µm and at 0.3mm/rev feed, surface roughness decreased to 2.71 µm. So surface roughness is improved when minimum feed rate is taken in the case of flake graphite cast iron material property.

As feed rate increases surface roughness also increases.

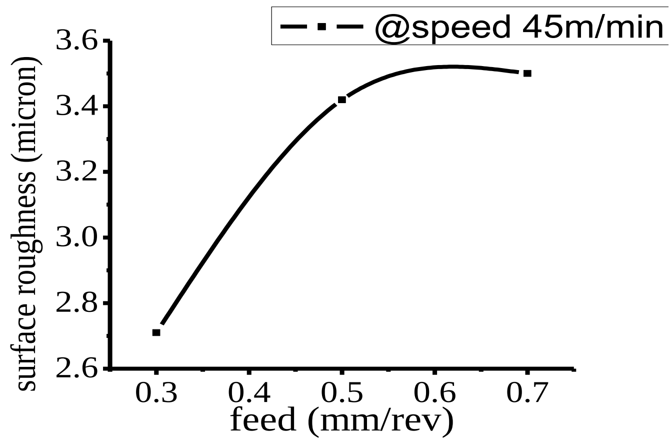

Figure 15. Effect of feed rate on surface roughness (Ra) at cutting speeds of 45m/min.

At 50m/min speed point of view surface roughness of 0.7 mm/rev is 2.64 µm, at 0.5mm/rev feed rate surface roughness is 2.61 µm and at 0.3mm/rev surface roughness is 2.13 µm as feed rate decrease surface roughness also improved.

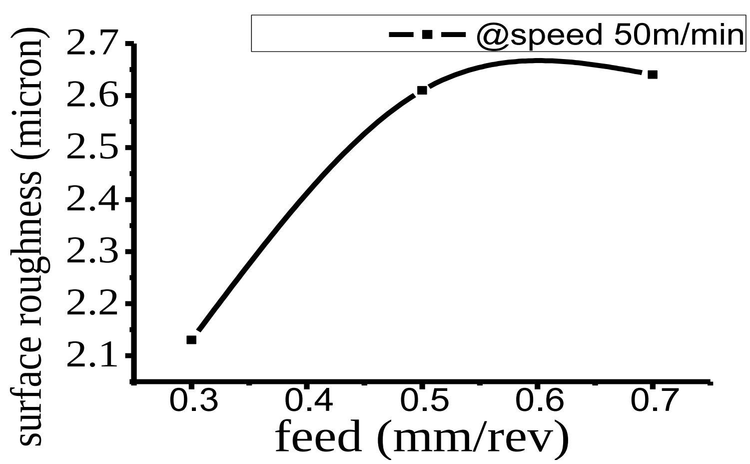

Figure 16. The effect of feed rate on surface roughness (Ra) at cutting speeds of 50 m/min.

At a cutting speed of 55 m/min as shown in Figure 17. the feed rate of 0.7m/min has a surface roughness of 2.37 µm, at 0.5m/min the surface roughness is 2.24 µm, and at

0.3mm/rev feed rate surface roughness is 1.97 µm. This value is the optimum surface roughness of the experiment.

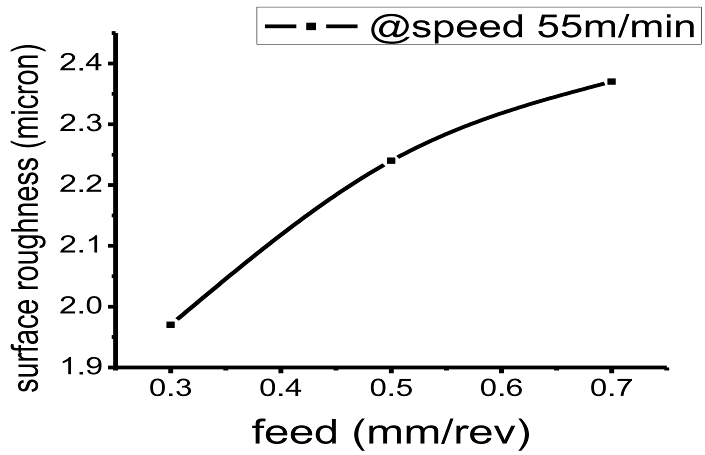

Figure 17. The effect of feed rate on surface roughness (Ra) at cutting speeds of 55m/min.

Similarly, as the depth of cut is 1.5mm the effect of surface roughness is 3.5µm, at the depth of cut is decreased to 1mm the effect of surface roughness is 3.42µm and at 0.5mm depth of cut the surface roughness effect is 2.71µm. As the depth of cut decreased surface roughness improved at 45m/min speed.

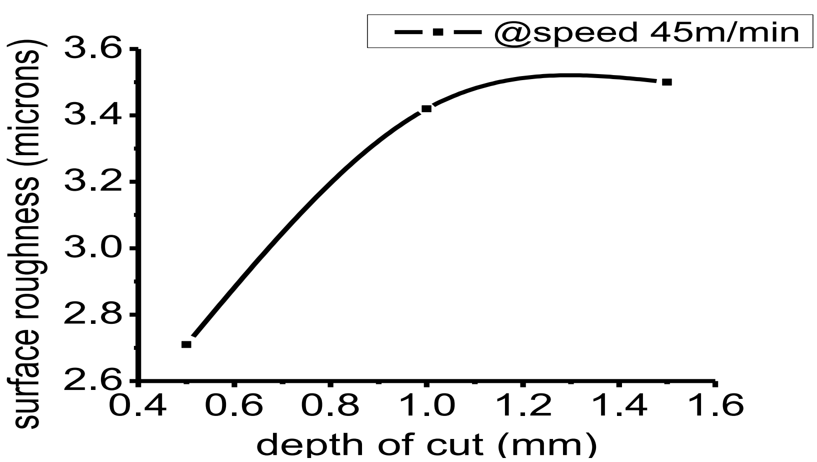

Figure 18. The effect of depth of cut on surface roughness (Ra) at cutting speeds of 45m/min

Figures 15-18, show the effect of feed and cutting speed on surface roughness. As increasing cutting speed from 45 m/min to 50 m/min, the surface roughness also improved at both constant feed 0.5 mm/rev and 0.7 mm/rev. But at 0.3mm/rev feed the surface roughness was slowly show progress initially with increasing cutting speed from 45 m/min to 50 m/min and then rapidly improved when cutting speed was increased to 55 m/min as shown in Figure. The reason for improved surface roughness was for reduced wear, low tooltip temperature, and friction as well as getting the product with high quality. Flake graphite cast iron does not have too much temperature incremental influence of tooltip due to plastic deformation behavior and nonlinear deformation of cast iron. Selection of cutting speed is based on making the best use of the cutting tool, which normally means choosing a speed that provides a high metal removal rate yet suitably long tool life. determine the optimal cutting speed for a machining operation, given that the various time and cost components of the operation are known. The optimal cutting speed is to be calculated for either of two objectives: (1) maximum production rate, or (2) minimum unit cost. Both objectives seek to achieve a balance between material removal rate and tool life. Maximizing Production Rate for maximum production rate, the speed that minimizes machining time per workpiece is determined. Minimizing cutting time per unit is equivalent to maximizing the production rate. This objective is important in cases when the production order must be completed as quickly as possible. It should be noted that throughout the discussion of optimization presented here, both labor and capital cost were included. This is consistent with the concept that productivity is not alone a matter of the output per man-hour but should take into account the capital involved in increasing output per hour. Figure 15 to 17 shows the effect of cutting speed for different feeds on the surface roughness. i.e. at 0.3mm/rev feed, at 0.5mm/rev and at 0.7mm/rev.The cutting speed 55m/min shows on the figure a maximum value and also optimum surface roughness investigation of flake graphite cast iron material property. Because a high amount of graphite lowers the material strength and less force can machine by minimum tool wear, temperature, and speed. Even though surface roughness of flake graphite cast iron is difficult it is induced ductility to some amount during dry turning which is approved by hardness testing after dry machining.

4.3.3. Predict the presentation at Optimal Levels of Mean Value

For predicting the optimum response, three factors of parameters are chosen by a small mean value. **A3B1C1** is the optimum level of parameters mean value for surface roughness value. To find out the predicted value of the responses (surface roughness value) the following linear regression equation is used:

$$y_{0pt} = m + (mA3 - m) + (mB1 - m) + (mC1 - m) \quad (4.1)$$

Where, m = Average performance mean value for surface roughness, $mA3$ = optimum level value for parameter A, $mB1$= optimum level value for parameter B, $mC1$= optimum level value for parameter C.

$$y_{0pt} = 2.62 + (2.19 - 2.62) + (2.37 - 2.62) + (2.60 - 2.62)$$

$y_{0pt} = 1.92$ (predict the mean value for surface roughness value)

4.3.4. Analysis Of S/N Ratios for Surface Roughness

The Taguchi method uses the S/N ratio to measure the variations of the surface roughness value in the investigational plan. The equations for calculating the signal-to-noise ratios are based on the behavior of the response variables being reported. In this thesis, the response variables are smaller-the-better. Table 8. presents the calculations of S/N Ratios for surface roughness value results using the design of experiments. And table 10. presents the reply table for a signal to noise ratio for smaller is better for this study. An example of calculation for the response table for the signal-to-noise ratio is as follows.

An example calculation is shown for factor B (feed):

$$S/N_{B1} = \frac{(-8.66)+(-6.57)+(-5.89)}{3} = -7.04$$

$$S/N_{B2} = \frac{(-10.68)+(-8.33)+(-7.00)}{3} = -8.67$$

$$S/N_{B3} = \frac{(-10.88)+(-8.43)+(-7.49)}{3} = -8.93$$

Table 10. Response Table for a Signal to Noise Ratios smaller is better

Level	speed	feed	Depth of cut
1	-10.074	-7.039	-8.032
2	-7.777	-8.673	-8.248
3	-6.796	-8.936	-8.368
Delta	3.277	1.897	0.336
Rank	1	2	3

$$Delta = (Maximum\frac{S}{N}ratio - Minimum\frac{S}{N}ratio)$$

By looking at the surface roughness response table (Table 10) and main effect plot for the signal to noise (S/N) ratios the cutting speed weight percentage has the greatest effect (Delta = 3.277, Rank = 1). The factor with the least effect on the (S/N) ratio is a depth of cut (Delta = 0.336, Rank = 3). Table 10. shows that the optimal parameter combination on smaller is the better surface quality character is **A3B1C1** are the likely parameter combinations for mounting the surface quality of specimens.

The control factors' main effect plot for the surface roughness SN ratios plot is shown in figure 19.

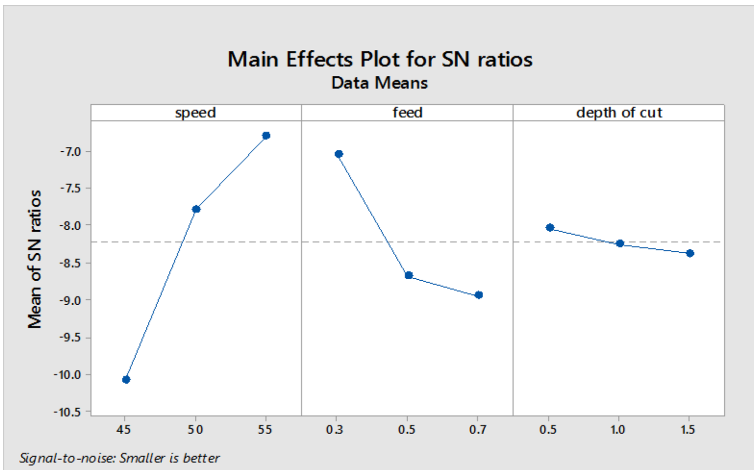

Figure 19. The main effects of the plot for SN ratios mean

The numerical value of the maximum point in each graph shows the best value of that exacting parameter at that level. They also point out the optimum conditions in the range of the experimental conditions. The most effective parameter to enhance the surface roughness is the cutting speed weight percentage when compared with other cutting factors and the depth of cut has the least effect on the surface roughness. Since the S/N ratio used for this study is smaller is better and the smallest S/N ratio was selected as is shown in Figure 19. That is cutting speed at level 3, feed at level 1, and depth of cut at level 1 (A3B1C1) was selected.

4.3.5. Predict the presentation at Optimal Levels S/N Result

For predicting the optimum response just about, three factors of parameters are selected by low S/N ratio value. **A3B1C1** is the optimum level 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 used:

$$y_{0pt} = m + (mA3 - m) + (mB1 - m) + (mC1 - m)$$

$$y_{0pt} = -8.33 + (-6.80 - (-8.33)) + (-7.04 - (-8.33)) + (-8.03 - (-8.33))$$

$y_{0pt} = -\ 5.21$ (predictS/N value for surface roughness)

4.3.6 Analysis of Variance (ANOVA) For Surface Roughness

Analysis of variance (ANOVA) is used to recognize the most important factors which affect the surface roughness of the machined part. It was calculated and reported in Table 11. Percent contributions for each factor were calculated by equation (3.4). Where DOF= degree of freedom, SST=Total sum of squares, SSTR = Treatment Sum of squares, MSE = Mean square error, and F = F- Ratio calculated by using Minitab 18 software.

Table 11.Analysis of variance (ANOVA) for surface roughness value

Source	DF	SST	SSTR	F-Value	P-Value	%of contribution	significance
Speed	2	1.66722	1.66722	86.43	0.011	72.93	Very significant
Feed	2	0.56436	0.56436	29.26	0.033	24.45	significant
Depth of Cut	2	0.04162	0.04162	2.16	0.317	1.75	Less significant
Error	2	0.01929	0.01929				
Total	8	2.29249					

Table 11. presents surface roughness percentage input variation of factors A, B, and C; where factors represent cutting speed, feed, and depth of cut respectively. It is observed that only the cutting speed factor has statistical and physical significance on the surface roughness value during cutting parameters at a 95% confidence level. From table 10. it is observed that cutting speed reason has statistical and physical significance on the surface roughness value during

turning operation of flake graphite cast iron at 95% of the level of confidence. From Table 11, practically, the cutting speed weight percentage (72.93%), feed (24.45%), and depth of cut (1.75%) have significant authority on the surface roughness of flake graphite cast iron specimens. Therefore, cutting speed has a significant effect parameter on the surface roughness of flake graphite cast iron in dry turning practice. A researcher as reported by [13],[42] identified the most significant factors that affect the surface roughness of cast iron alloy material

4.3.7 Determining the Optimum Condition

From Table 8 and Table 9, it is observed that cutting speed influences percentage optimum level value 55m/min, feed optimum level value 0.3mm/rev and depth of cut optimum level value 0.5mm make the answer S/N ratio values small. Therefore, the optimum processing parameters signal to noise (S/N) ratio was selected. Table 10. presents the optimum parameters setting selected for surface roughness obtained from the design of the experiment and experimental results. The preferred optimum parameters in this study were at higher cutting speed, at medium feed, and at lower depth of cut which, is at A3B1C1.

Table 12.Optimum parameters setting levels and their values

Controllable factors	Level selected	Value of level	The rank of affecting the response
Cutting speed	3	55	1
Feed	1	0.3	2
Depth of cut	1	0.5	3

3.4. Confirmation Test

Once the optimal combination of process parameters and their levels was obtained, the final step was to confirm the predicted result against the experimental result. If the optimal combination of parameters and their levels coincidently match with one of the experiments in the Orthogonal Array, then no confirmation test is required. By bearing in mind this, a Confirmation test was required in this case study because the optimum combination of parameters and their levels **(A3B1C1**) have a reporter to an experiment of the orthogonal array of the trail 7 conditions of the experiment. The obtained optimal factor combination is one of the trial conditions (Trial 7) and (Trial 8) of the experiment. Thus, the mean is calculated by averaging the response values of that trial. The Optimum combination of parameters obtained from Table 12. was at 55m/min Cutting Speed, 0.3mm/rev Feed, and 0.5mm Depth of cut. Table 13. presents the confirmation experiment and predicted results comparison for surface roughness measurements.

Table 13.Comparison between predicted and experimental confirmation.

Response	Optimal parameter	Predicted value		Experimental value	
Surface Roughness (μm)	A3B1C1	Mean	S/N	Mean	S/N
		1.92	-5.21	1.97	-5.89

It can be seen from Table 13 the result between the experimental result and the predicted results is very small. The values predicted by using the Taguchi approach are roughly near to the value which is experimentally obtained. This verifies that the experimental results of surface roughness are strongly associated with the predicted outcome.

4.5 Analysis of Material Removal Rate

Material removal rate (MRR) is the quantity of material removed per time unit. Conventional Machining Processes mostly remove material in the form of chips by applying forces on the work material with a wedge-shaped cutting tool that is harder than the work material under machining conditions, the outcome of end cast iron turning better material removal rate was obtained. The material removal rate can be calculated by using equation (2.3). The amount of materials removed during the cast iron turning process experiment is determined and listed in Table 4.6.MRR=speed of cutting ×feed rate× depth of cut, which gives the value of optimum material removal rate at an optimum time calculated also from the formula t=length of workpiece/feed rate × spindle speed. The maximum (MRR) can be obtained by a combination of high feed rate and speed of cut and limited by the factors of the depth of cut, tools nose under consideration and machine tools power are the factors limiting materials removal rate.

Table 14.The analysis of the amount of material removal rate.

experiment.	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	MRR (mm3/min)
1	45	0.3	0.5	6750
2	45	0.5	1	22500
3	45	0.7	1.5	47250
4	50	0.3	1	15000
5	50	0.5	1.5	37500
6	50	0.7	0.5	17500
7	55	0.3	1.5	24750
8	55	0.5	0.5	13750
9	55	0.7	1	38500

As observed in Table 14. And figure 20 the material removal rate is affected by cutting speed, feed, and depth of cut. With the increase in cutting parameters the material removal rate increased. The superior cutting parameters, the higher the material removal rate achieved. This can be justified by the relation shown in equation (2.3). On the other hand, these cutting parameters also affect the surface worth of the machined part, tool wear, and cutting temperature. Due to the above-mentioned reasons, the cutting parameters are needed to be limited. Therefore, machining parameter optimization is highly essential. Based on experimental outcomes the material removal rate obtained at optimum cutting parameters was 24750mm3/min. It removes workpiece material in a single cut rather than a long-lasting cylindrical grinding and remains competitive. In addition, since the optimum cutting speed at which the best surface finish is obtained is at the highest level values, both the enhanced surface finish and material removal rate are achieved. In machining, a higher material removal rate doesn’t mean economical machining because it affects tool life. However, the economical machining will be achieved at optimized parameters for which tool wear is low, tool life is more, surface finish is good. The figure below indicates the influence of feed of rate on material removal rate

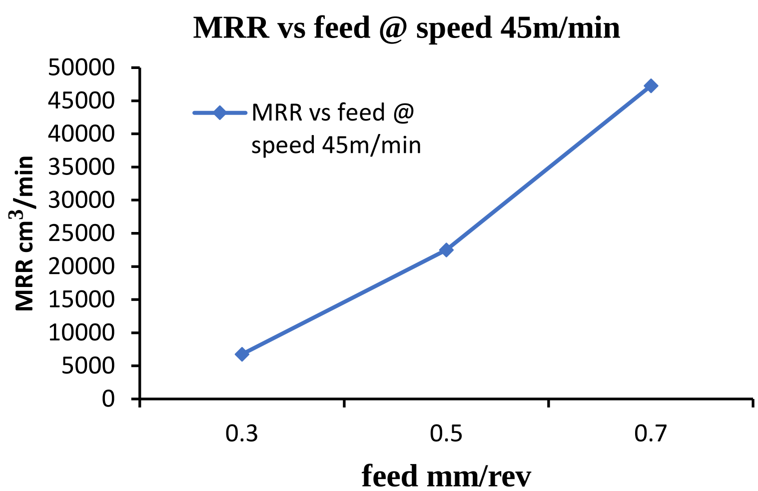

Figure 20. The effect of MRR on feed rate at speed 45 m/min

The influence of depth of cut on the material removal rate is shown in figure 21. The material removal rates increase with an increase in the depth of cut. But due to the continuous increase in depth of cut have a shock on surface roughness, tool wear, and tooltip temperature it was limited. As feed rate increase from 0.3 mm/rev to 0.5mm/rev and 0.7 the material removal rate is increasing from very low to very high removing rate at speed of 45m/min. At 50m/min speed the material removing rate is also very low at 0.3mm/rev. The optimum material removing rate is obtained at 55m/min. According to an experiment value shown on the graph, the optimum depth of cut and material removing rate is obtained at 0.3mm/rev feed rate and 24750mm^3/min consecutively. So the high material removing rate and low material removing rate is not optimum because low material removing rate is not cost-effective economically and also high material removal is good but it may cause machine tool vibration and chutter of the cutting tool which may lead to surface roughness defects as well as an unoptimized result may appear.

The figure below shows the effect of depth of cut on material removal rate at feed rate.

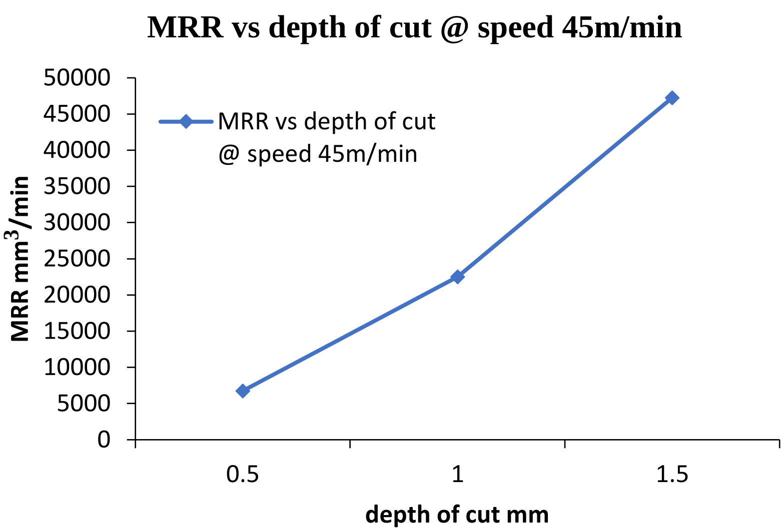

Figure 21. The effect of MRR on the depth of cut at feed rate.

It is observed that the material removal rate increases with an increase in depth of cut, feed rate, and cutting speed. But in finishing the flake graphite cast iron operation the material removal rate which gives high surface quality, high tool life, and bridges the gap between quality and productivity is very important by dry turning operation. In this study, the optimum material removal rate of 24750mm^3/min at the optimum cutting condition with low flank wear, the low surface roughness of 1.97µm, and the low cutting temperature of 75.^{0}c were achieved.

4.7. Analysis of Tool wear

Tool life is defined as the length of cutting the time that the tool can be used. Operating the tool until the final disastrous failure is one way of defining tool life. This is indicated by tool wear. Wear is the result of the four wear mechanisms: surface fatigue; abrasion; tribology chemical reaction; and adhesion. These mechanisms show the way to material and form alterations, and also to the arrangement of wear particles, and take place in the form of distinguishing wear phenomena. The four wear mechanisms are distinguished by the wear characters of the experiment described below. Although each wear mechanism can occur single-handedly, the assessment of wear smash-up indicates that there is practically always a superposition of several wear mechanisms, which complicates any wear analysis and wear hindrance. chemically, how such a superposition might come into view; frequently, the individual wear mechanisms will reciprocally reinforce each other. The nature of tool wear during the turning of flake graphite cast iron has been studied and presented in this section. The mechanism of tool wear in the tooltip has been presented based on the time taken during the dry turning operation of the experiment. the tooltip of the cutting tool inserts has taken at different cutting parameters. The pattern of tool wear is almost the same at different cutting parameters and their combinations. This is due to varying degrees of the effect exerted by the cutting speed; feed rate and depth of cut tell almost the same wear patterns. Tool wear measurements of flank wear are taken using a micro meter of cutting tool employed in turning of cast iron under dry cutting condition machining after completion as shown below.

Table 15. The experimental data of tool wear in the flank wear

experiment.	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Flank wear (mm)
1	45	0.3	0.5	0.06
2	45	0.5	1	0.07
3	45	0.7	1.5	0.1
4	50	0.3	1	0.068
5	50	0.5	1.5	0.071
6	50	0.7	0.5	0.92
7	55	0.3	1.5	0.05
8	55	0.5	0.5	0.065
9	55	0.7	1	0.095

The experimental data of tool wear in the flank wear is also shown by the figure at a speed of 55 m/min which is applied on flank wear during cutting operation of flake graphite cast iron material is done experimentally as shown below which also narreted in [49].

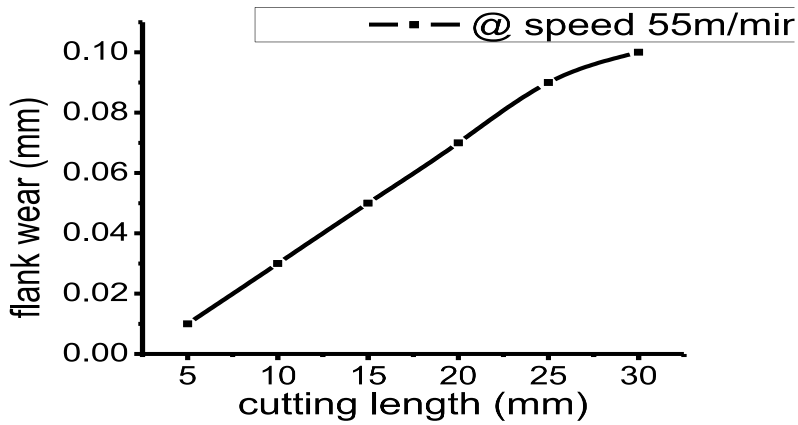

Figure 23. The effect of cutting length on tool wear at speeds 55m/min.

As explained in [15] Flake graphite tool life is high because of material has a less average temperature. It has abrasive wear as a dominant wear mechanism since dry machining conducting. It is micro-plowing: definite plastic deformation of the material by the abrasive counter-body gives rise to a pile-up at the edge of the guide, so that material abrasion is not forced to occur. It has no wear noticed and because machining is proceeding by the lowest resultant force. Flake graphite cast iron reduces the stress load on the tool during machining. Cutting fluid can increase the tool life but decrease the cutting force this is the case why a dry machining study is conducted in [15],[45]. The length of each workpiece is 30 mm. For each workpiece, the same ceramic-coated carbide tool is used. The sample measurement of the cutting tool is taken by using a micro meter instrument after turning is shown in table 15. The optimum cutting parameter of speed 55m/min sample experimental measurement value is also shown in figure 23 above.

4.8. Observation of Chip Morphology

Chip formation has become a technology in its own right which has shown significant development over the last few decades of machining. Chip formation and its resultant morphology are not only affected by the cutting parameter selected but also influenced by the cutting tools and inserts. The main type of chips formed during machining flake graphite cast iron is fragmented chips. The chips are formed as very small rubbish which can voluntarily be cleared from the cutting area even when machining at very far above the ground speeds. It is to some amount dirty and sandy action, throw a fine scatter of graphite into the air, so that fortification for factory employees may be necessary, in dry turning operation of this study. Figure 24. shows the chips formed in the dry turning process of flake graphite cast iron for all nine different experiments conducted in this study. Due to the presence of graphite element in the cast iron alloy the chips produced were discontinuous type as shown in Figure 24.

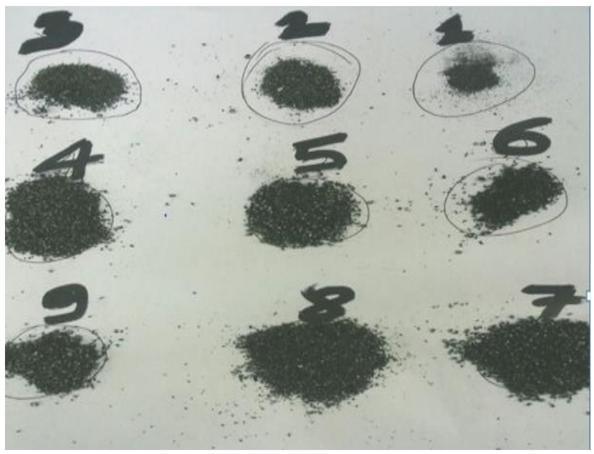

Figure 22. Chips formed during machining flake graphite cast iron

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In the current work, the rapport between surface roughness and various process parameters namely cutting speed, feed, and depth of cut has been conducted.

- Taguchi method has been adopted for the design of experiments and the results have been analyzed by least S/N ratio of machining parts of dry turning process of flake graphite cast iron.
- L_9 orthogonal array was selected, for three factors each at three levels.
- Analysis of variance used to conclude the percent involvement of each parameter on the surface finish of the machined part by dry turning practice.
- Based on the investigation of variance (ANOVA) outcome, the cutting speed was the largest factor for improving surface roughness whereas the depth of cut was the least essential.
- A parameter aim gives the optimum circumstance of the restricted parameters and analytical equation. A confirmation method is then performed, which shows that the preferred optimum parameters and analytical equation were precise to contained by the limits of the extent.
- Based on the experimentation work, the optimum cutting parameter achieved for flake graphite cast iron were 55m/min cutting speed, 0.3mm/rev feed, and 0.5mm depth of cut.

In this thesis, optimization methods have been utilized to establish the optimal dry turning parameters which affect the surface value of flake graphite cast iron in turning practice. The chief parameters that affect surface roughness have been known and analyze in diverse circumstances and lastly optimized. The major parameters being cutting speed, feed, and depth of cut. Based on the outcome the conclusion is strained as follows.

In turning of flake graphite cast iron for least surface roughness, utilize of superior cutting speed (55m/min), intermediate feed (0.3mm/rev), and low depth of cut (0.5mm) were chosen. That is

A3B1C1 is optimized to acquire small surface roughness which is the elevated surface finish of the machined piece.

The involvement of the majority of important parameters such as cutting speed was 72.9%, feed 24.62% and depth of cut was 1.75%.

The foremost benefit of this research work recommends the option of dry machining which accumulates charge of machining and also contributes to green environmentally safe manufacturing.

5.3 Recommendations

- Based on the outcome and conclusions that originate from these lessons, the researcher forwards the following recommendations in the machining of flake graphite cast iron.
- In this study flake graphite cast iron has been using. This can be extra comprehensive to other types of cast iron alloys to revise the result of cutting parameters on the surface roughness in the identical circumstance of turning parameters.
- The study can be unlimited by a range of parameters and their relations and the mechanical study can also be carried out.
- This study was restricted to a single reaction only. Though, a multi-response optimization of machining parameters for surface roughness can use and analyzed.
- The study can be unmitigated by employing double tool turning to improve productivity.
- For cast iron alloys dry machining is extremely suggested in machining industries.

5.2 Scope for Future Work

In this research only three cutting parameters have been studied by their effects, the further researcher can be carried out to; In this revision, only the cause of cutting parameters on the surface roughness was calculated due to, the difficulties for measure the cutting force (unavailability of dynamometer) and difficulties for measure the machine vibration frequencies (unavailability of the accelerometer) which are significant factor those affects the surface roughness of the machined part would be analyzed and optimized. Analyses the effect of cutting forces exert and tool wear rate throughout the cutting action. Study the effect of special cutting tools with comparable cutting parameters.

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Appendices

Taguchi Design

Design Summary

Taguchi Array	L9(3^3)
Factors:	3
Runs:	9

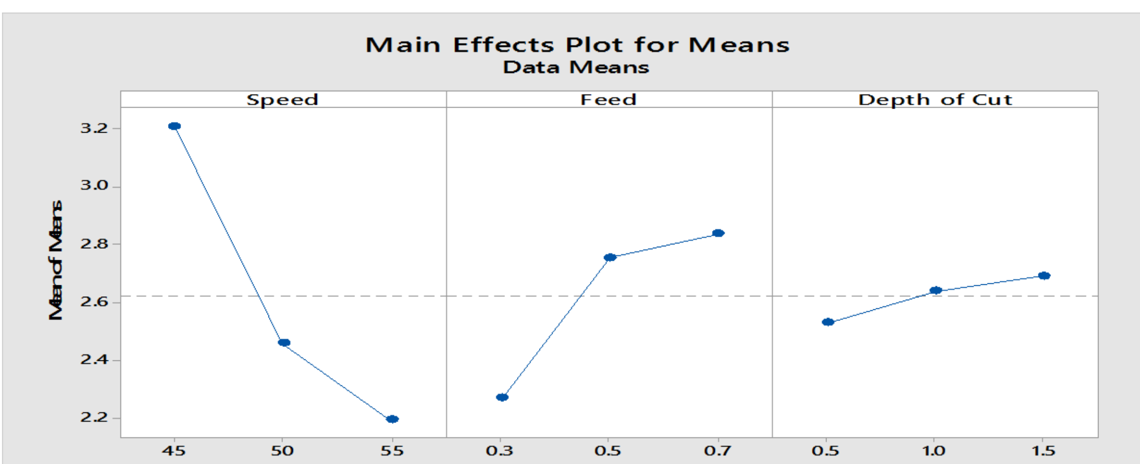
Columns of L9(3^4) array: 1 2 3

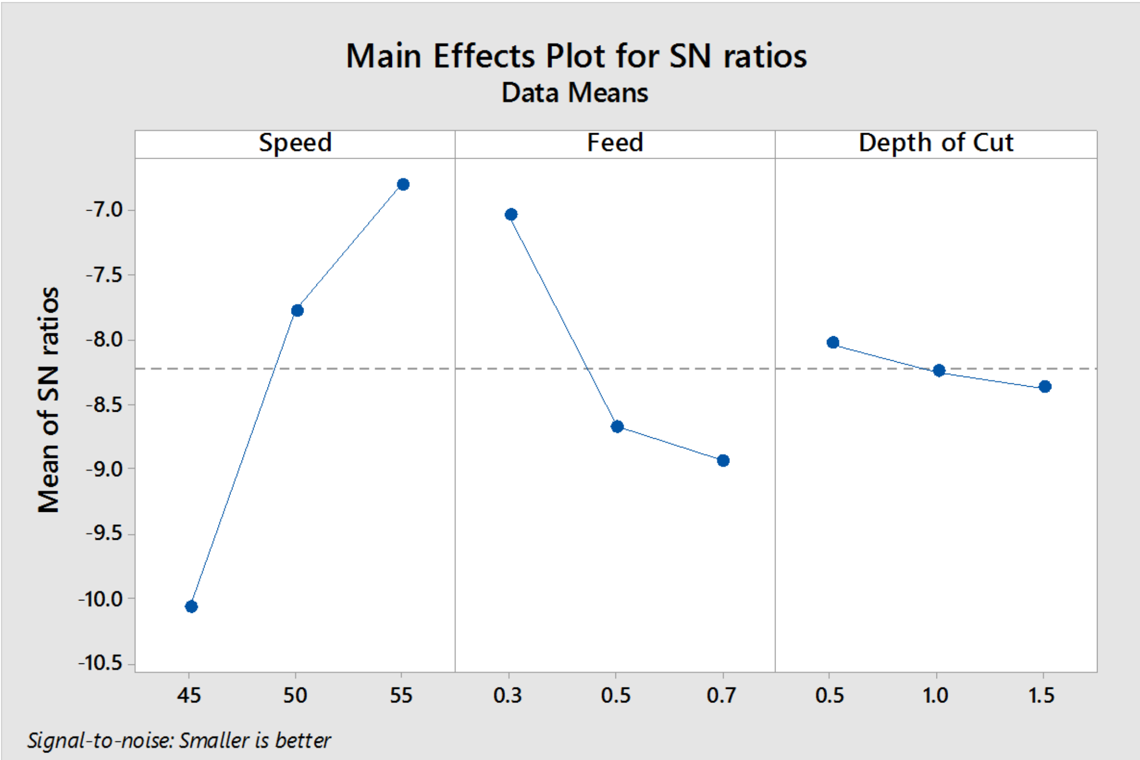
Taguchi Analysis: Ra versus Speed, Feed, Depth of Cut

Response Table for Signal to Noise Ratios and means

Smaller is better

Level	Speed	Feed	Depth of Cut
1	-10.074	-7.039	-8.032
2	-7.777	-8.673	-8.248
3	-6.796	-8.936	-8.368
Delta	3.277	1.897	0.336
Rank	1	2	3





Speed	Feed	Depth of Cut	Ra	SNRA1
45	0.3	0.5	2.71	-8.65939
45	0.5	1	3.42	-10.6805
45	0.7	1.5	3.5	-10.8814
50	0.3	1	2.13	-6.56759
50	0.5	1.5	2.61	-8.33281
50	0.7	0.5	2.64	-8.43208
55	0.3	1.5	1.97	-5.88932
55	0.5	0.5	2.24	-7.00496
55	0.7	1	2.37	-7.49497

General Linear Model: Ra versus Speed, Feed, Depth of Cut Method

Factor coding	**(-1, 0, +1)**

Factor Information

Factor	Type	Levels	Values
Speed	Fixed	3	45, 50, 55
Feed	Fixed	3	0.3, 0.5, 0.7
Depth of Cut	Fixed	3	0.5, 1.0, 1.5

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed	2	1.66722	0.833611	86.43	0.011
Feed	2	0.56436	0.282178	29.26	0.033
Depth of Cut	2	0.04162	0.020811	2.16	0.317
Error	2	0.01929	0.009644		
Total	8	2.29249			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0982061	99.16%	96.63%	82.96%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.6211	0.0327	80.07	0.000	
Speed					
45	0.5889	0.0463	12.72	0.006	1.33
50	-0.1611	0.0463	-3.48	0.074	1.33
Feed					
0.3	-0.3511	0.0463	-7.58	0.017	1.33
0.5	0.1356	0.0463	2.93	0.100	1.33
Depth of Cut					
0.5	-0.0911	0.0463	-1.97	0.188	1.33

1.0	0.0189	0.0463	0.41	0.723	1.33

Regression Equation

Ra	=	2.6211 + 0.5889 Speed_45 - 0.1611 Speed_50 - 0.4278 Speed_55 - 0.3511 Feed_0.3 + 0.1356 Feed_0.5 + 0.2156 Feed_0.7 - 0.0911 Depth of Cut_0.5 + 0.0189 Depth of Cut_1.0 + 0.0722 Depth of Cut_1.5