INVESTIGATION OF CUTTING FORCES AND CHIP FORMATION CHARACTERISTICS IN ORTHOGONAL MACHINING OF ALUMINIUM.

BY

YUSUF, Ibrahim

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DEPARTMENT OF MECHANICAL ENGINEERING

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

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ABSTRACT

In the last century, a large amount of research has been done to study and understand the various machining processes with a view to improving the processes for further economic (cost and productivity) gains. However, many aspects of the cutting processes and cutting performance remain to be fully understood in order to increase the cutting capability and optimize the cutting processes. Cutting is a process of extensive stresses and plastic deformations. The high compressive and frictional contact stresses on the tool face result in a substantial cutting force F. Cutting forces are the background for the evaluation of the necessary power in machining (choice of the electric motor). They are also used for dimensioning of machine tool components and the tool body. They influence the deformation of the work piece machined, its dimensional accuracy, chip formation and machining system stability. The aim of this work is to study the influence of feed rate, and tool rake angle and depth of cut on the main cutting force and chip morphology during a turning process, Aluminium alloy 6061 was used as workpiece material. In total,27 experiments were performed in order to measure the main cutting force (F_c). The experiments were performed with cutting depths of 0.5mm, 1.0mm and 1.5 and cutting speeds of 71, 90 and119 m/min, three different feed rates of 0.15, 0.20 and 0.25 mm/ rev. and three different rake angles 18^o, 20^o and 28^o. During the experiment, the removed chips were collected and evaluated together with the main cutting forces. The experimental results showed that main cutting force has an increasing trend with the increasing of the feed rate between 0.05 to 0.7 mm rev. In contrast, the main cutting force has a decreasing trend as the rake angle increases from 0^o to 20^0. There were indications that deformation occurred during the machining process, though the chip is generally continuous, chip length decreases as the cutting speed and feed rate increases. The experiment was done with the optimum of 12^o rake angle for specimen.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Kadrigama et al (2005) stated that, cutting force is one of the most important factors for metal cutting process. Metal cutting process is common and important process for machining and fabrications.

For a long time, manufacturing engineers and researchers have been realizing that in order to optimize the economic performance of metal cutting operations, efficient quantitative and predictive models that establish the relationship between a big group of input independent parameters and output variables required for the wide spectrum of manufacturing processes, cutting tools and engineering materials currently used in the industry according to them.

Armarego (1994) observed that the improvement in the output variables, such as tool life, cutting forces and surface roughness, through the optimization input parameters, such as feed rate, cutting speed and depth of cut, may result in a significant economic performance of machining operations.

One of these output variables that may have either direct or indirect effect on other variables such as tool wear rate, machined surface characteristics and machining cost, is cutting forces. Many researchers have conducted studies on predicting cutting forces produced in machining operations using theoretical and analytical Approaches. Strenskowski et al (1987) and affirmed by Shih et al (1993).

On the other hand, many other researchers have followed purely experimental approaches to study the relationship between cutting forces and independent cutting conditions. This has reflected on the increased total cost of the study as a large number of cutting experiments is required. Furthermore, with this purely experimental approach, researchers have investigated the effect of cutting parameters on cutting forces using machining experiments based on a one-factor-at-a-time design, without having any idea about the behavior of cutting forces when two or more cutting factors are varied at the same time. Kadrigama et al (2005)

The knowledge of cutting forces developing in the various machining processes under given cutting factors is of great importance, being a dominating criterion of material machinability, to both: the designer-manufacturer of machine tools, as well as to user. Furthermore, their prediction helps in the analysis of optimization problems in machining economics, in adaptive control applications, in the formulation of simulation models used in cutting databases. Petropoulos et al (2005).

In this regard, cutting forces being a substantial dependent variable of the machining system has been investigated by many researchers in various cutting processes through formulation of appropriate models for their estimation.

1.2 Significance of study

The relationship found between high speed machining and chip, morphology, and the cutting forces and workpiece surface finish has an important practical implication since it allows selecting the best cutting condition combination from the points of view, both for the security and the economy for the established requirements in each case. Results are of great importance in selection of parameters that aid in tool design, considering machining as an economic activity that is a compromise between observed parameters, (Abu, 2009). Similarly the knowledge of cutting force facilitates the:-

- Estimation of cutting power consumption, which also enables selection of the power source(s) during design of the machine tools
- Structural design of the machine – fixture – tool system
- Evaluation of role of the various machining parameters on cutting forces
- Study the machinability characterization of the work materials

1.3 Justification of study

In machining industries and Research and Development sections, the cutting forces are desired and required to be measured (by experiments):

- for determining the cutting forces accurately, precisely and reliably (unlike analytical method),
- for determining the magnitude of the cutting forces directly when equations are not available or adequate,
- to explore and evaluate role or effects of variation of any parameters, involved in machining, on cutting forces, which cannot be done analytically.

1.4 Objectives of Research

- Understand the basic mechanics of chip formation,
- Investigate the Effect of Rake angle on the Cutting Forces
- Investigate the Effect of Depth of cut on the cutting forces
- Investigate the Effect of Feed rate on the cutting forces
- Investigate the Effect of cutting speed on the cutting forces

1.5 Scope

For the purpose of this work, Aluminum Alloy 6061was used as workpiece material turning operation was carried out on lathe machine. This due to the fact that is the least expensive and most versatile of the heat-treatable aluminum alloys, It has most of the good qualities of aluminum. It offers a range of good mechanical properties and good corrosion resistance. It can be fabricated by most of the commonly used techniques. In the annealed condition it has good workabilityand this grade is used for a wide variety of products and applications from truck bodies and frames to screw machine parts and structural components. 6061 is used where appearance and better corrosion resistance with good strength are required.

At variable Speeds and depth of cut three cutting tools with different rake angles will be selected with three selected feed rates (0.15, 0.20 and 0.25). Each experiment will be carried out with new sharp tools in order to keep the cutting conditions unchanged. The cutting-test were conducted without coolant and, as a result, totally 27 experiments will be performed. Dynamical forces (both vertical and horizontal) will be measured and results evaluated, while types of chips formed are being collected and measured.

1.6 Research Methodology

Tyan etal (1992).Manufacturing technology has been a driving force behind modern economics since industrial revolution (1770). Metal forming processes, in particular, have created machinery and structures that permeate almost every aspect of human life today. Although manufacturing techniques have become more sophisticated, many process and tool design are still based on experience and intuition. Advances in computer and material sciences have greatly enhanced our ability to develop predictive capability and to achieve the goal of optimization for a wide variety of application.

In achieving the main objective of this research work will be achieved through the following

- Defining the selected parameters
- Measure cutting Forces
- Analyze cutting force
- Discussing the results

CHAPTER TWO

2.0 LITERATURE REVIEW

According to Mohammad (2000), in the cutting process, as shown schematically in figure 2.1; a hard tool is pressed into a softer Workpiece material, producing a chip and machined surface. The material undergoes severeplastic deformation in passing through a highly localized shear zone extending from the tip ofthe tool to the free surfaces at the juncture of chip and undeformed workpiece, called primaryDeformation zone.

He further stated that ,depending on the cutting speed, the deformation may occur at very high strain rates. When the cutting tool moves through the workpiece material, the chip is separated from the workpiece and slides over the rake face of the tool. The highly pressurized friction between the chip and the rake face causes further straining of the material in the area around thetool surface called secondary deformation zone. In this region, the chip initially sticks to the tool, but with the reduction of pressure further up on the rake face, it slides over the tool face elastically until it separates from the tool and curls away.

The plastic deformation and friction generate large amount of thermal energy in the cutting zones, which raises the temperature in the cutting zones significantly, sometimes beyond the re-crystallization temperature of the metal. Such temperature rise has the effect of softening of the material, in contrast to the hardening effects of large strains and high strain rates, the process variables are dependent on cutting conditions and tool geometry which bring about large variety to the process.

Mohammad (2000) further describes machining as one of the most common manufacturing processes, nearly every mechanical Component in use has undergone a machining operation at some stage of its manufacturing process. Therefore, the economics of metal cutting process significantly affects the overall cost of final products, and there is a strong drive to reduce the time and the cost of machining operations. In the past century, a great deal of research has been devoted toward understanding the mechanics of metal cutting, with the objective of obtaining more effective cutting tools and more efficient manufacturing process plans.

Traditionally, these objectives have been achieved by experimentation and prototyping. In spite of extensive research in this field, the basic mechanics of the cutting process and the interplay of many factors which leads to its great variety are not yet totally understood, and the search for more effective models has continued on analytical, experimental and numerical fronts. He went further to say that, Metal cutting is a complex process, in which several mechanisms are at work simultaneously, and interact with each other.

This process is greatly affected by material properties, cutting conditions, and tool geometry and machine-tool dynamics. In practical machining operations, such as various turning and milling operations, the geometry and kinematics of the tool is very complex. For this reason, traditionally, a much simplified model of cutting, the orthogonalcutting, is used in the fundamental study of mechanics of this process.

Molinari and Moufki (2004) stated that, in industry, high speed machining is frequently used to remove unwanted material from a workpiece and obtain desired geometrical dimensions and surface finish. However, it is not obvious how to select the cutting conditions which may result in high productivity rates and small workpiece surface error since competitive use of the machining option requires high speed machining and high metal removal rates. Main factors that limit process optimization in machining are the tool wear and a phenomenon called chatter which is a dynamic instability limiting material removal rates, causing poor surface finish and damage of the tool and workpiece.

Empirical methods are often used to determine process parameters such as tool selection, cutting speeds and feed rates. This leads to solutions which are often sub-optimal. In order to optimize manufacturing performance, the interactions between cutting conditions, tool, workpiece and the phenomena governing the chip formation process have to be understood through experimental studies, modeling and simulation.

The analysis of metal cutting is usually restricted to a simple case corresponding to cutting with a straight cutting edge whereas in industrial machining processes, the tool presents a complex geometry. During cutting, the cutting edge of the tool is positioned at a certain distance below the original work surface. This corresponds to the chip thickness prior to chip formation, as the chip is formed along the shear plane, its thickness increases to the ratio called chip thickness ratio, and is always less than 1.

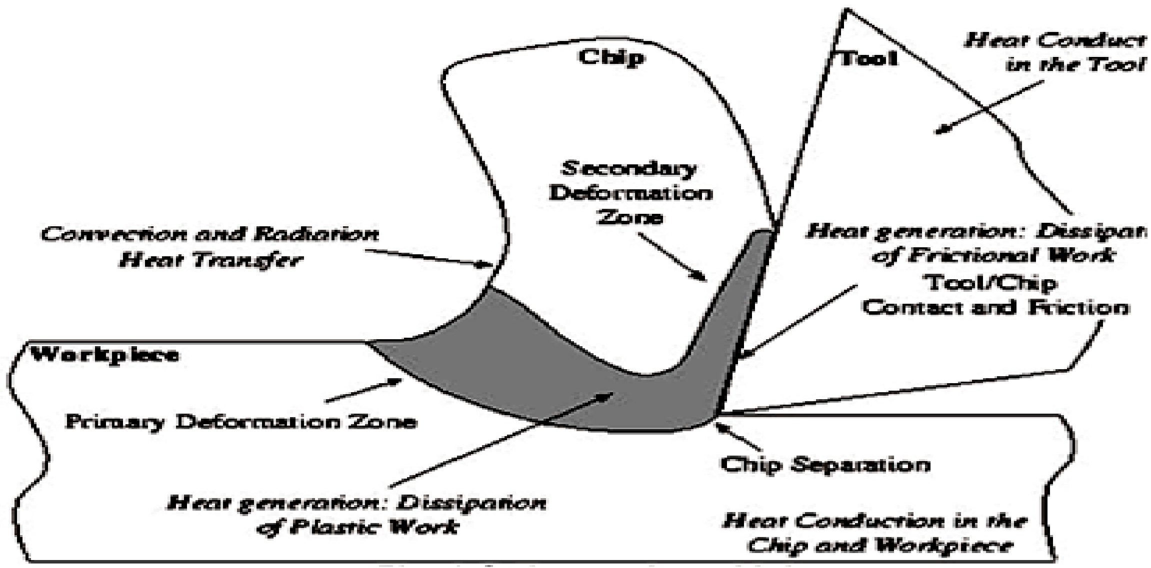


Fig. 2.1 Machining Process (Source: - www.sme.org)

2.1 MECHANICS OF METAL CUTTING

The first attempt to explain the mechanics of metal cutting was by Tresca, (1873). He describe the cutting process as one of compression ahead of tool this accounted for chip length ,being shorter than workpiece together with a shearing on the plane parallel to the surface of work which separate the chip from the work .

Geofrey (1975) further cited that, at the same time another scientist called Timmepointed out that , the material is not being compressed ahead of the cutting tool but it is sheared and the plane along where shearing takes place is called " shear plane "and the angle which this makes with the plane of generated surface was termed "shear angle" . Timme also obtained correct expression for the ratio of the chip length to the workpiece length in terms of the geometry of the process and justify it experimentally.

Analytical investigation of the cutting process made much progress in the first half of the century. In 1937**,** Piispanen presented the card model which depicts the shearing of the material as a deck of cards inclined to the free surface. In the early 1940's, Ernst and Merchant developed their classic shear plane model based on free body diagram of the chip which is held in equilibrium by two equal, opposite and collinear resultant forces, one acting on shear plane, and the other on the rake face of the tool.

The Merchant's circle below shows the relationship between various force and velocity components acting on the chip. In this figure, $V_{c,}$ $V_{s,}$and V_w are chip velocity, shearing velocity and workpiece velocity, respectively, R is the resultant force on the tool with its projections in shear and in frictional directions, α , $\emptyset$and β, are rake, shear and friction angles, respectively, l_c is the contact length, and $t_o$and $t_1$are uncut chip thickness and chip thickness, respectively. The shear plane model assumes that the deformation of the material ahead of the tool occurs instantaneously on a thin plane of concentrated shear, the shear plane, and that shear and normal stresses are uniform on this plane. Across the shear plane, velocity of the workpiece material is instantaneously changed to the chip velocity. They obtained the angle between the shear plane and cutting direction, the shear angle, by making the shear plane a direction of maximum shear stress which affect the cutting process, such as hardening, rate and temperature effects, sticking sliding friction and more complex tool geometry.

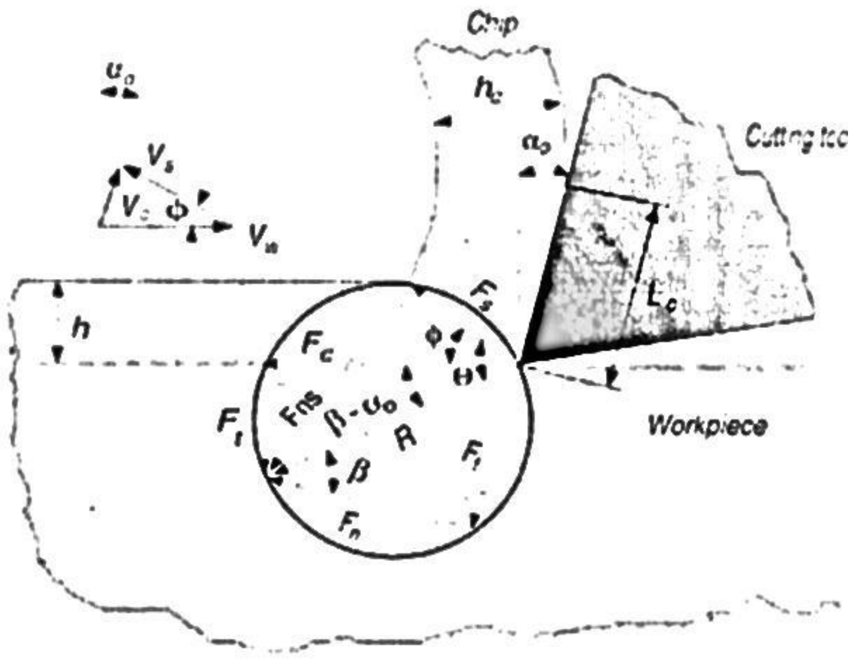


Fig. 2.2 Relationship between force and velocity components (Source: Mohammed, 2000).

The worksof Shaw et al (1953), Johnson and Mellor (19730, Oxley and Coworkers (1989), and Armarego (1969), are noteworthy in this area. Palmer and Oxley (1959) used experimental flow fields obtained by tracing the path of individual grains in low speed cutting to determine the extent of the deformation zone and the shear angle. They showed that the plastic deformation zone has substantial thickness and the streamlines form smooth curves from the workpiece into the chip. They developed slip-line field solutions from the experimental results and calculated the stress distribution in the deformation zone. Oxley and Welsh (1963) developed a parallel-sided shear zone theory which allows for strain hardening of the material. In this model, the shear flow stress changes from initial yield stress at the lower boundary of the shear zone to a higher value at its upper boundary. Later, Stevenson and Oxley (1971) developed more comprehensive models by using a power law flow stress equation whose coefficients were dependent on strain rate and temperature. These effects were combined using the concept of velocity-modified temperature, and it was suggested that the flow stress for a particular material at a given strain can be assumed to be a unique function of this parameter.

Oxley (1989) laid out a predictive theory of orthogonal machining based on the above chip formation model. There have been attempts to find shear angle solutions for 3-D oblique cutting process by Usui etal (1978), and Shamoto and Altintas (1997) Seehaler and Yellowley (1997) presented an upper bound solution for oblique cutting tools with a nose radius.

Ren and Altintas (1999) obtained a slip-line field solution for cutting with chamfered edge tools. Jawahir etal (1993) have studied chip curling and breaking using analytical and numerical methods. A successful cutting model should be able to incorporate such effects. A reliable model of material behavior at such extreme conditions is an essential input to cutting simulation. However, the strain rate and temperature in the cutting process are orders of magnitude higher than what could be measured by most of existing measurement equipment, and thus, direct data about material behavior at conditions similar to what occurs in cutting process is hardly available. Many other phenomena may occur in a cutting process such as various types of chips obtained in different cutting conditions, creation of built-up edges, tool wear and dynamic effects such as chatter.

However, the basic mechanism of formation of the chip in the deformation zones and the interplay of various factors in this process remain at the core of the fundamental research on mechanics of metal cutting. In the last century, understanding of cutting mechanics has caught the attention of many researchers, and many analytical, empirical and numerical models have contributed to knowledge in this field. While all of these models have advanced the common knowledge about the cutting process, the ultimate usefulness of a cutting model is in its ability to predict the process variables for a given set of cutting conditions with reasonable accuracy and cost.

In particular, numerical modeling of this process has attracted the attention of many researchers in recent years, because of the better insight it can provide into the mechanics of chip formation by voiding many of the simplifications needed in other approaches. There is a prospect that one day; such simulations may replace costly machining tests needed for tool design and process planning. However, the reliability of a numerical cutting model is dependent on two factors; the reliability of the input data in terms of material and frictional characteristics, and the correctness and efficiency of the numerical approach, formulation and procedures used.Kadrigama et al (2005)

2.2 METHODS OF METAL REMOVAL

The two methods of cutting as identified by Jain et al (2010) are orthogonal and oblique, or two - dimensional and three- dimensional respectively. The orthogonal cutting process takes place when the cutting edge is perpendicular to the cutting velocity vector or to the direction of movement of the tool.

Similarly,Cyril et al (2006) state that for experimental purposes, metal cutting has been classified as either orthogonal or oblique, the simplest is the orthogonal cutting process where the tool is set with its cutting edge perpendicular to the direction of the tool travel, and only a straight cutting edge is active experimentally. This type of cutting is accomplished by planning the cutting edge of the plate with a tool wider than the thickness of the plate.

Radford (1978) also added that, in orthogonal cutting the tool approaches the workpiece with its cutting edge parallel to the uncut surface and at right angle to the direction of cutting .To prevent end effects; the tool is wider than the workpiece. All theories of orthogonal machining imply or assume a plane strain condition, in that the width of the chip remains equal to the width of the workpiece.

This theory is usually attributed to Merchant, although other investigators have independently arrived at a similar conclusion. Plane oriented at an angle φ (shear angle) with the surface of the workpiece. Along the shear plane,plastic deformation of work material occurs.The tool in orthogonal cutting has only two elements of geometry.

Rao (2000), basically there are two methods of metal cutting depending upon the arrangement of the cutting edge with respect to the direction of relative work – tool motion.

2.2.1 Orthogonal or Two Dimensional Cutting Model

It is a simplified 2-Dmodel that describe the mechanics of machining fairly accurately .

- In orthogonal cutting, the relative velocity of the work and tool is perpendicular to the cutting edge, it has the following characteristics:
- The cutting edge of the tool remains at 90^0 to the direction of feed.
- The chip flow in the direction normal to the cutting edge of the tool.
- The cutting edge of the tool has zero inclination normal to the feed

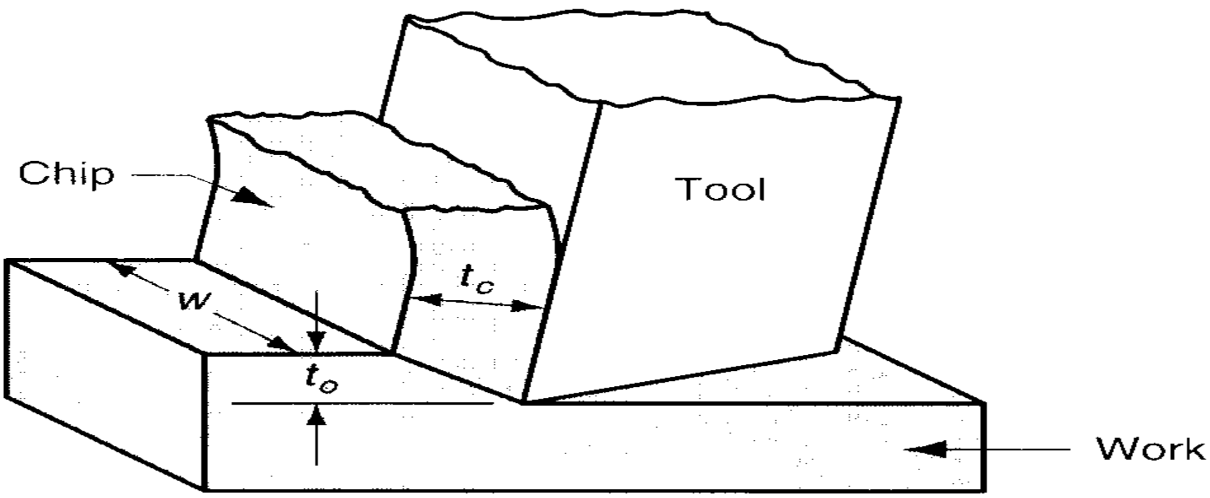


Figure 2.3a Orthogonal cutting, as a three-dimensional process.(Source : Groover, 2007)

2.2.2 Oblique Method or Three Dimensional Cutting

When the relative velocity of the work and tool and the tool is not perpendicular to the cutting edge, this process is known as Oblique method or three dimensional cutting.It has the following characteristic:

- The cutting edge of the tool remains inclined at an acute angle to the direction of the feed.

- The direction of chip flow is not normal to the cutting edge rather it is at an angle **β** to the normal to the cutting edge.
- The edge is inclined at an angle **λ** to the normal to the feed .this angle is called inclination angle.

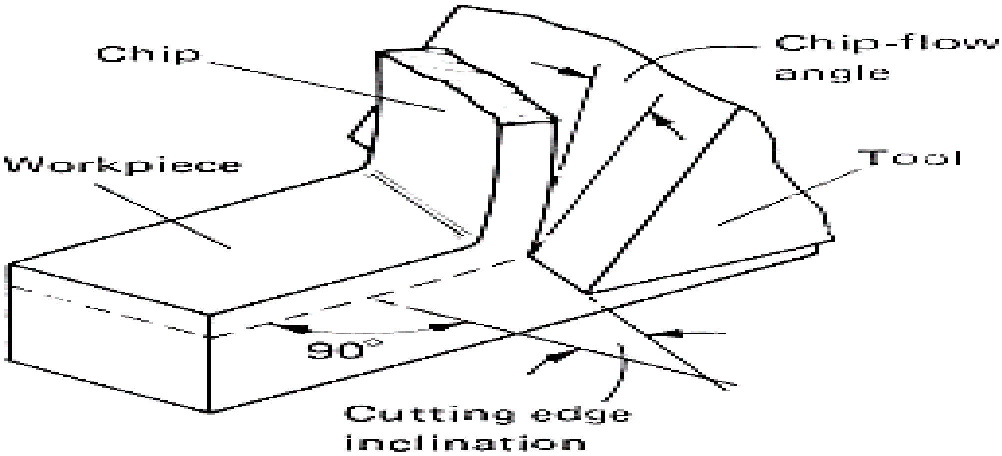


Fig.2.3b Oblique cutting(Source :Groover, 2007)

2.3 TURNING PARAMETERS

The Majority of turning operations involve simple single point cutting tool, such tools are described by a standardized nomenclature. Each group of tool and workpiece material has an optimum set of tool angle which were developed largely through experience.

2.3.1 Tool geometry:

The various angles used have important function in cutting operation.

Rake angle: (**α**)is important in controlling the direction of chip flow and the strength of the tool tip. Positive angles improve the cutting operation by reducing forces and temperatures. However, positive angles produce small included angles depending on the toughness of the tool material; this may cause premature tool chipping and failure.

Side rake angle is more important than **back rake angle,** although the later usually controls the direction of chip flow.

Relief angle control interference and robbing at the tool- workpiece interface .if the relief angle is too large , the tool may chip off; if too small , the flank wear my be excessive .

Cutting edge angles affects chip formation, tool strength and cutting forces to various degrees.

Nose edge angles affect. Surface finish and tool tip strength, also the sharper the radius the rougher will be the surface finish of the workpiece and the lower will be the strength of the tool, However, large nose radii can lead to tool charter Kalpakjian (1997)

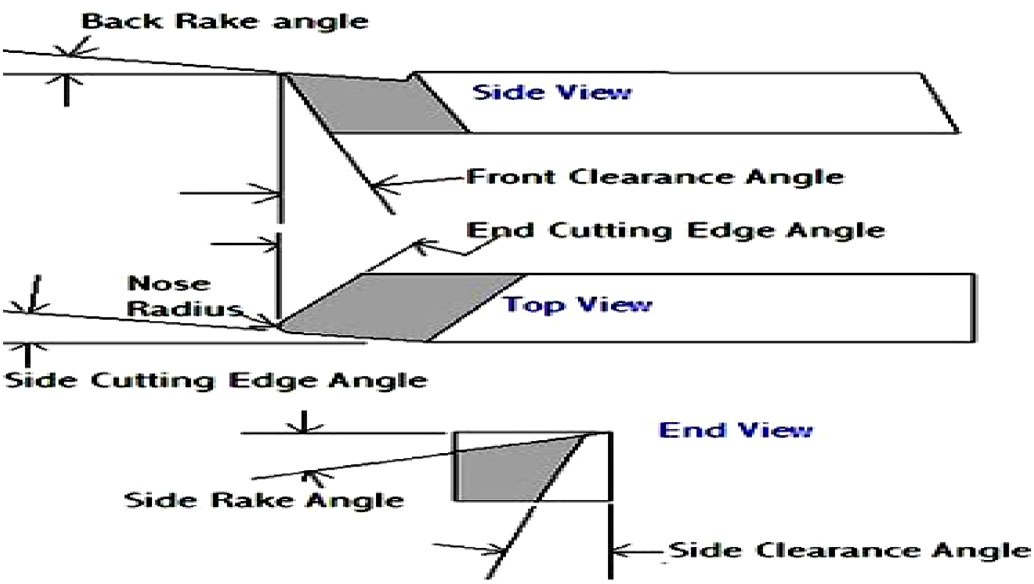


Fig. 2.4 Tool Bit Geometry (Source: on site 23rd January 2012)

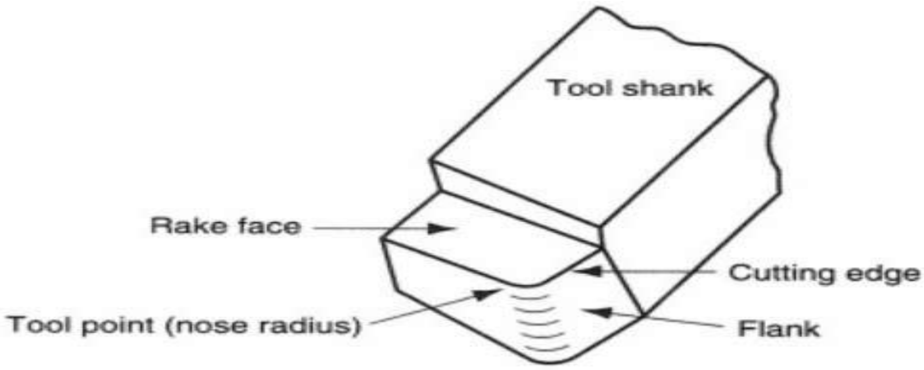
2.4 Cutting Tool Classification

Single-Point Tools

i. One dominant cutting edge

ii. Point is usually rounded to form a nose radius

iii. Turning uses single point tool



2.2.2 Multiple Cutting Edge Tools

I. More than one cutting edge

II. Motion relative to work achieved by rotating

III. Drilling and milling use rotating multiple cutting edge tools.

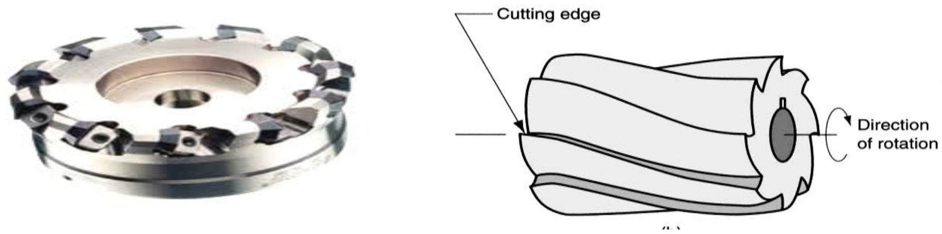


Fig. 2.6 Multi Tooth Cutting tool (Source:Groover, 2007)

2.5 CUTTING CONDITIONS IN MACHINING

Degarmo et al (2001) stated that, an understanding of what the process parameters are is necessary in order to design and operate machining processes, to specify machine tools and tooling and to use machining process models. Process models can be used to predict the effects of process parameter changes on process performance. So they are useful for process design and process improvement. An important aspect of using process models is to understand the relationship between the usually simplified model and its parameters and the real physical process being modeled. An example of using a realistic, but simplified, model is the use of the orthogonal machining model to describe the turning process.

Lathe turning has a simpler configuration than many other machining operations, yet includes all the important characteristics of most machining processes. To clarify the definitions of the process parameters a schematic diagram of the turning process with the capability of changing cutting conditions is presented.

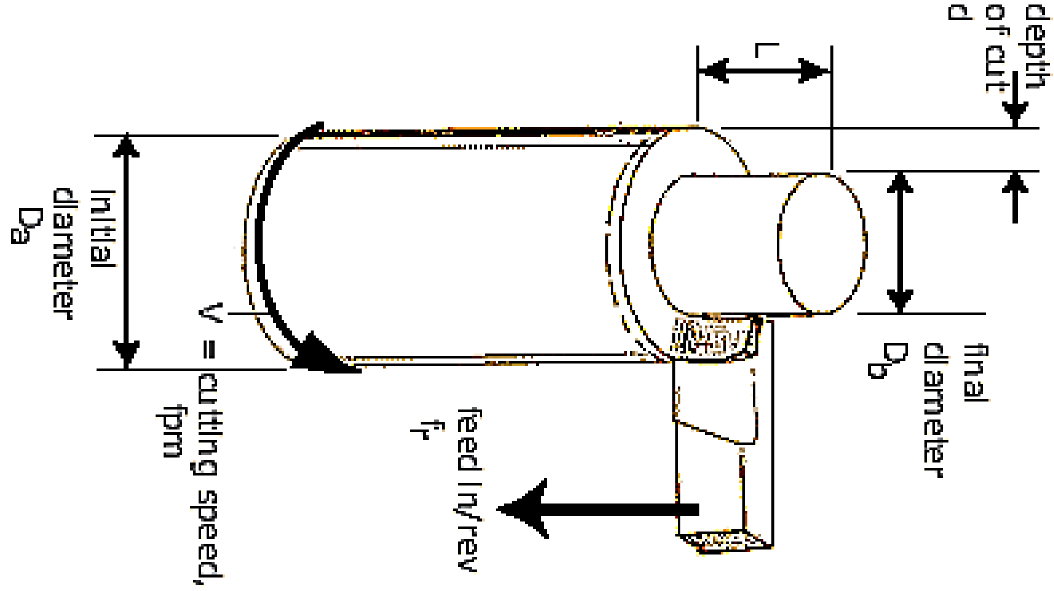


Fig. 2.7 Cutting conditions (Source: on site 23rd January 2012)

For everymachining operation , it is necessary to select the best combination of the three primary cutting parameters which are :

- Cutting speed v- The velocity –(primary motion)at which the workpiece moves past the tool or at which the tool moves past the workpiece ;expreesed in mm/mins;

- Feed f – the distance the tool advances longitudinally or into the work piece for each revolution of the workpiece ;mm/rev;
- Depth of cut d– The normal distance from the original cutting surface to the freshly cut surface or Penetration of tool below original work surface expressed in mm.

Of the three varieblesmensionedabove , cutting speed influences tool life by the greatest amount , Tylor (1907). So great is this effect thattylor developed the following equation

$$VT^n = C \tag{2.1}$$

Where :

V = Cutting Speed

T = Tool life

n = Dimensioness constant depending on tool and work piece varieable

C = Dimensioness constant depending also on tool and work piece varieable ; numerical equal to the cutting speed giving one minute tool life.

Upon examining these equation , it is obvious that as speed increases tool life decreases exponentially .

Of the two remaining machining variebles , Cook (1966) states that feed has more effect on tool life than depth of cut.

If these two variebles are incorporated into a tool life equation , the resulting equation is

$$V\, T^{n} d^{x} f^{y} = C \qquad (2.2)$$

Where

V = Speed

d = Dept of cut

f = Feed rate

x,y = Dimensioless constant again depending on workpiece and tool variables . ASME (1962)

Many factors impinge on these dicisions because all of the depending variebles are influenced by them .proper selection of variebles also depends on the other input variebles that has been selected ; that is the total amount of material to be removed.

For certain operations, material removal rate can be computed as

$$R_{MR} = v\, f\, d \qquad (2.3)$$

Where

R_{MR} =metal removal rate

v = cutting speed;

f = feed and

d = depth of cut

2.6. MACHINING AND MACHINABILITY.

Probably one of the best ways to evaluate the efficiency of metal cutting operation is to relate the ease of machining to different condition which affects the process. The commomnly used term to express this relationship is machininbilityrating.This rating is normally expressed as a percentage and is usually determined by comparing how the workpiece material under consideration under machines with respect to a standard material SAE B1112 steel .given a rating of 100 percent.

In evaluating the machinability rating of metal , the following criteria may be considered:

- Magnitude of cutting foce on the tool .
- Quality of the workpiece surface finish
- Life of cutting between resharpening, under standardize conditions
- Form and size of chips .
- Power consumption of the machine.
- Cutting temperature
- Rate of cutting under standard force
- Rate of metal removal . Black (1961)

Surface finish is also an important consideration but not often taken into account in machingcalculation . The machining operation is set up using previously determined values of metal cutting variables and resulting surface finish is noted . If the finish is not acceptable the process variebles are changed until until the finish meets specification .Normally , surface finish will improve with increase in cutting speed , decrease feed decrease depth of cut, increase workpiece temperature and improve friction condition between the work and tool, Lambart (1968)

Tool life is the primary machinability factor controlling the cost of cutting operation, and for this reason mos machinability rating of workpiece material are based on tool life values

MACHINING AND MACHINABILITY OF ALUMINIUM.

Aluminum alloys are among the most commonly used lightweight metallicmaterials as they offer a number of different interesting mechanical and thermal properties. In addition, they are relatively easy to shape, especially in material removalprocesses, such as machining. In fact, aluminum alloys as a class, are considered as thefamily of materials offering the highest levels of machinability, as compared to other families of light weight metals such as titanium and magnesium alloys. This machinability quantifies the machining performance, and maybe magnesium alloys. This machinability qualifies machining performance and may be defined for a specific application byvarious criteria, such as tool life, surface finish, chip evacuation, material removal rate andmachine-tool power. It has been shown that chemical composition, structural defects andalloying elements significantly influence machinability.

Konig et al (1983). Thus, with similar chemical compositions, the machinability of alloys can be improved by differenttreatments. Heat treatments, which increase hardness, will reduce the built-up edge (BUE) tendency during machining, Tash et al (2006). In the case of dry machining, the majorproblems encountered are the BUE at low cutting speeds and sticking at high cuttingspeeds, hence the need for special tool geometries,Roy et al(2008). It has been shownthat high levels of Magnesium (Mg) increase the cutting forces at the same level of hardness,while a low percentage of Copper (Cu) in aluminium alloy 319decreases the cutting force,Tash et al (2006). Similarly, it has been found that heat treatment of 6061,especially aging, influences the forces only at low cutting speeds, while at high speeds; theinfluence is negligible because of the low temperature rise seen in the cutting zone Demir et al (2008). Cutting force is just one among several parameters to be considered for a fullassessment of the machinability of metallic alloys, with the others being the tool life, thesurface finish, the cutting energy and the chip formation mode.Aluminum alloys are classified under two classes: Cast alloys and Wrought alloys.

Furthermore, they can be classified according to the specification of the alloying elements involved, such as strain-hardenable alloys and heat-treatable alloys. Most wrought aluminum alloys have excellent machinability. While cast alloys containing copper, magnesium or zinc as the main alloying elements can cause some machining difficulties, the use of small tool rake angles can however improve machinability. Alloys having silicon as the main alloying element involve larger tool rake angles, lower speeds and feeds, makingthem more cost-effective to machine. Aluminum alloys, which are not sensitive to heat treatments, can be hardened by cold work that can improve their machinability when sharptools are used.

2.8. MECHANISM OF CHIP FORMATION

According to Kalpakjian(1997),cutting process, such as turning on the lathe, drilling, and milling remove material from the surface of the workpiece there by producing chips. The basic mechanics of chip is essentially the same for all these operations.

Cutting action involves shear deformation of work material to form a chip

As chip is removed, new surface is exposed

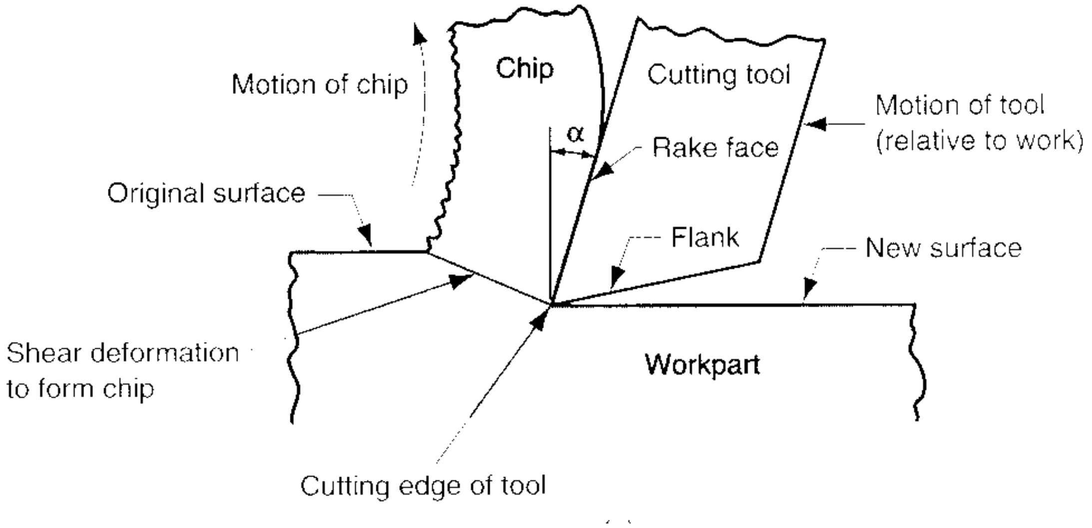


Fig. 2 .8 Chip Formation model

Jain et al (2010) opined that, irrespective of the basic nature of chip obtained during machining of metals, the main factor governing the formation of chips is the plastic deformation of the metal by shear process. According to him, in 1945 Merchant used an idealized concept of chip formation, for which a precise geometry may be taken to be the basis of his studies of the mechanism of chip formation.

In developing the geometry, the following assumptions were made:

- The process can be adequately represented by any two dimensional cross section of the cut,
- The tool is perfectly sharp and contacts the chip only on its front or rake face,
- The primary deformation takes place in very thin zone adjacent to the shear plane,
- The cutting edge is perpendicular to the cutting velocity vector and
- The chip does not flow to the sides.

Kalpakjian (1997) further identified the following as the major independent and dependent in metal cutting process

2.8.1. Independent variables–are those that can be change directly.

- Tool material and its condition
- Tool shape ,surface finish and sharpness
- Cutting condition
- Use of cutting fluid
- Characteristics of the machine tool

2.8.2 Dependent variable- are those that are influenced by changes in the independent variables, and they are:

- Type of chip produced
- Force energy dissipated in the cutting process
- Temperature rise in the workpiece , the chip and the tool
- Wear and failure of the tool and
- The surface finish produced , on the workpiece after machining

2.9. CHIPS `FORMATION CHARACTERISTICS IN METAL CUTTING

When we observe chip formation under different metal cutting condition, we find significant deviation from the type of chips formed which can be classified as

2.9. 1. Continuous Chips

- Ductile work materials
- High cutting speeds
- Small feeds and depths
- Sharp cutting edge
- Low tool-chip friction

2.9. 2. Discontinuous Chip

- Brittle work materials
- Low cutting speeds
- Large feed and depth of cut
- High tool-chip friction

2.9. 3. Continuous Chip with Build up Edge

- Ductile materials
- Low-to-medium cutting speeds
- Tool-chip friction causes portions of chip to adhere to rake face
- BUE forms, then breaks off, cyclically

It should be noted that a chip has two surfaces: one in contact with the tool face and the other from original of the workpiece. The tool side of the chip surface is shining, or burnished, which is caused by rubbing of the chip as it climbs up the tool face. The other surface of chip does not come in contact with any solid body. This surface has a jagged steplike appearance, which is caused by shearing mechanism of chip formation Kalpkakjian, (1997).

2.10. GEOMETRY OF CHIP FORMATION

Jain et al (2010) stated that, the formation of all basic types of chip can be describe with the help of geometrical mode derived from photomicrographs. The tool moves with a velocity $V_c$against the work and there by shears the along a plane , the out coming chip of thickness $t_c$experience two velocity components V_f and V_s along thetool face and shear plane respectively. The depth of cut is t_o whichis actually the feed in machining operation. From the geometry of chip, it is possible to compute the value of shear angle ∅ in terms of measurable t_o,t_c andα which in turn fully defines the model of continuous chips.

2.10.1 Determination of chip geometry

Two experimental methods have been used in order to discover the way in which chips are formed. In one of these, the cutting process is stopped suddenly to leave the chip attached to the workpiece and in contact with the tool. This gives still picture of chip formation, which probably suffers some distortion due to elastic recovery when the cutting stress is released. The second method is high speed photography, which enables a ‘‘slow motion ‘‘film of the of the chip formation to be made. The method has been employed by air craft company, the region around the cutting edge of the tool is viewed through a microscope so that chip formation may be examined in detail.

2.11. Cutting Forces in Turning

Malagi and rajesh (2012) stated that the knowledge of cutting forces devlopin in various machining processes under given cutting factor is of great importance being a dominating criterion of material machinability to both : the designer – manufacturer of macine tools as well as the user.

Degarmo et al(2001) confirmed that, at the most basic level; cutting forces depend on the properties of the work material and on how the work material is deformed in the chip formation process. The workpiece deformation is not directly controllable. However, work material deformation can be influenced by process parameters. Some of these process parameters are directly controllable while others are not. For example, cutting tool shape can be changed within reasonable limits so that the tool maintains sufficient strength. A less controllable process characteristic that influences deformation in chip formation, and also temperature, is the tool-chip coefficient of friction. While cutting fluids can be applied to change the coefficient of friction, a specified friction coefficient cannot be exactly and reliably specified and produced. The three forces acting on the cutting tool as shown in the figure below the cutting force $\mathbf{F_c}$acts downward on the tool tip and tends to deflect the tool downward, this is force that supplies the energy required for the operation.

The thrust force $\mathbf{F_t}$acts as in the longitudinal direction;this force is called feed force because it is in the feed direction. The radial force $\mathbf{F_r}$is in the radial direction and tends to push away the tool from the workpiece .Forces $\mathbf{F_t}$and $\mathbf{F_r}$are difficult to calculate because of many factors involved in the cutting process, so they are determined experimentally. These forces are important in the design of machine tools as well as in the deflection of tools for precision machining.

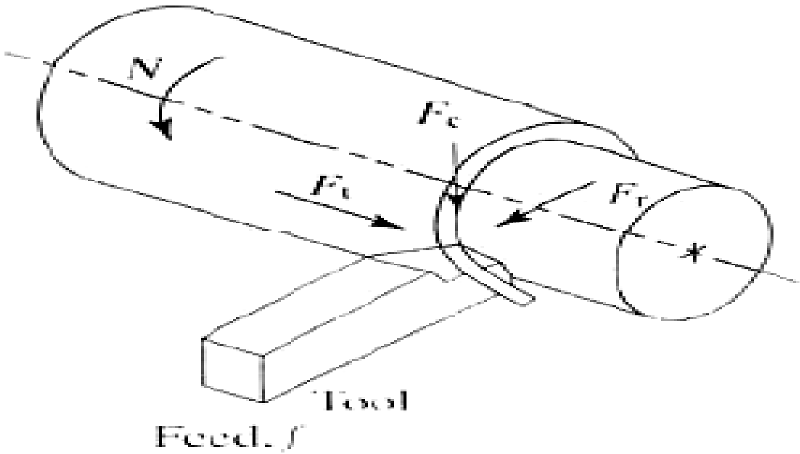


Fig: 2.10. Forces in Turning: (Source: Kalpkakjian, 1997)

2.11.1 Determination Cutting Force

Cutting forces are either measured in the real machining process, or Predicted in the machining process design.

2.11.2 Measurement of cutting forces

The measurement of cutting forces is performed either by measuring directly the deformation due to the cutting force or by measuring the transformed deformation by a transducing element. Direct force indicating dynamometers are of mechanical type, with deformation being picked up by dial indictors, the basic scheme of a two dimensional mechanical type dynamometer can be seen below indicating the direction of the vertical and horizontal force component $P_x$and P_z respectively.

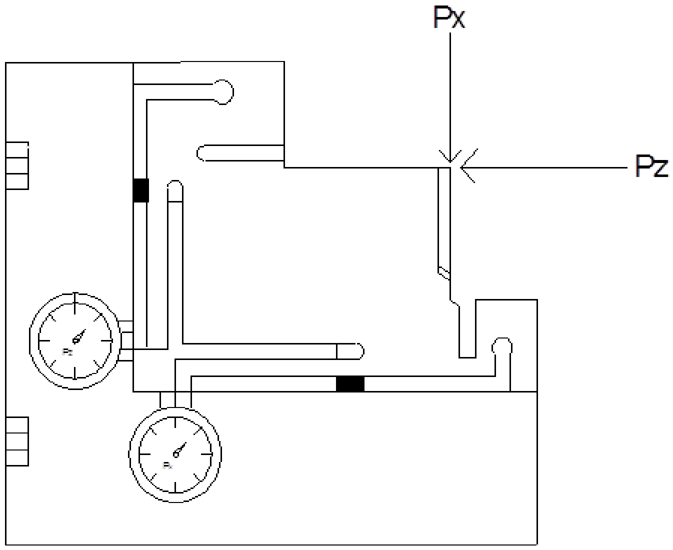


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Fig.2. 11. Mechanical type two dimensional dynamometer(Source: Jain, 2010)

2.11.3 Cutting force prediction

Marinov(2009) stated that, for cutting force prediction, several possibilities are available, For approximate calculations of sufficient accuracy for all practical purposes, the so-called specific cutting force (cutting force per unit area of cut) k_C is used: $F_C = k_C h_D b_D$

For small cut thickness and dull cutting tools $k_C$must be increased. The value of thrust force F_D is taken usually as a percentage of F_C. More advanced options for cutting force prediction are based on analytical or numerical modeling of metal cutting. Due to the complex nature of the cutting process, the modeling is typically restricted to orthogonal cutting conditions, although solutions for the three dimensional cutting are also available in other literatures.

2.11.4Cutting Force and Power

To machine metal at a specific speed , depth of cut and feed withn a specific lubricant , cutting tool and geometry generates cutting force and consumes power, a change in any of the variebles alters the forces,

A machining operation requires power, the power to perform machining can be computed from

$$P_c = F_c\, v \qquad (2.4)$$

where :

P_c = cutting power;

F_c = cutting force; and

v = cutting speed

In U.S. customary units, power is traditional expressed as horsepower (dividing ft-lb/min by 33,000)

$$HP_c = \frac{F_c v}{33{,}000} \qquad (2.5)$$

Where:HP_c = Cutting horsepower, hp

Power and Energy Relationships

Gross power to operate the machine tool P_g or HP_g is given by either of the two equations below.

$$P_g = \frac{P_c}{E} z \qquad HP_g = \frac{HP_c}{E} \qquad (2.6)$$

where$E$ = mechanical efficiency of machine tool typical E for machine tools ~ 90%

Unit Power in Machining

Useful to convert power into power per unit volume rate of metal cutcalled *unit power*, P_u or *unit horsepower*, HP_u

$$HP_u = \frac{HP_c}{R_{MR}} \qquad (2.7)$$

2.11.5 CUTTING TEMPERATURE

Analytical method derived by Nathan Cook from dimensional analysis using experimental data for various work materials

Analytical method derived by Nathan Cook from dimensional analysis using experimental data for various work materials

$$T = \frac{0.4U}{\rho C}\left(\frac{vt_o}{K}\right)^{0.333} \qquad (2.8)$$

where T = Temperature rise at tool-chip interface;

U = specific energy;

v = cutting speed;

t_o = chip thickness before cut;

ρC = volumetric specific heat of work material;

K = thermal diffusivity of work material

Approximately 98% of the energy in machining is converted into heat, this can cause temperatures to be very high at the tool-chip .The remaining energy (about 2%) is retained as elastic energy in the chip.

High cutting temperatures

- Reduce tool life
- Produce hot chips that pose safety hazards to the machine operator
- Can cause inaccuracies in part dimensions due to thermal expansion of work

material.

Experimental methods can be used to measure temperatures in machining

Most frequently used technique is the *tool-chip thermocouple*

Using this method, Ken Trigger determined the speed-temperature relationship to be of the form:

$$T = K v^m \tag{2.9}$$

where$T$ = measured tool-chip interface temperature, and v = cutting speed

2.12. Merchant – Ernst Analysis of Metal Cutting

In orthogonal cutting, the total cutting force F is conveniently resolved into two components in the horizontal and vertical direction, which can be directly measured.

If the force and force components are plotted at the tool point instead of at their actual points of application along the shear plane and tool face, we obtain a convenient and compact diagram. Several forces act during the cutting process. A normalized force diagram is shown below At the most basic level; cutting forces depend on the properties of the work material and on how the work material is deformed in the chip formation process. By using the concept of chip formation and by measuring the vertical and horizontal force component with a dynamometer, merchant was able to build up a picture of the forces acting in the region of cutting which give rise to plastic deformation and sliding of the chip down the tool. The theory assumes that a continuous type of chip is produced, Jain etal (2010).

For the purpose of modeling chip formation, assumed that the shear process takes place on a single narrow plane rather than on the setoff shear fronts that actually comprises a narrow shear zone . Further assume that the tools cutting edge is perfectly sharp and no contact is being made between flank of tool and new surface. The workpiece passes the tool with velocity V, the cutting speed, the uncut chip thickness t_o.Ignoring the plastic compression of chips having thickness $t_c$are formed by shear process, The chip has velocity V_c. The shear process then has velocity Vs and occurs at the onset of shear angle ø .the toolgeometry is given bythe back rake α angle the clearance angle.

The equations for analytical estimation of the salient cutting force components are conveniently developed using Merchant's Circle Diagram (MCD) when it is orthogonal cutting by any single point cutting tool like, in turning, shaping, planning, boring etc.

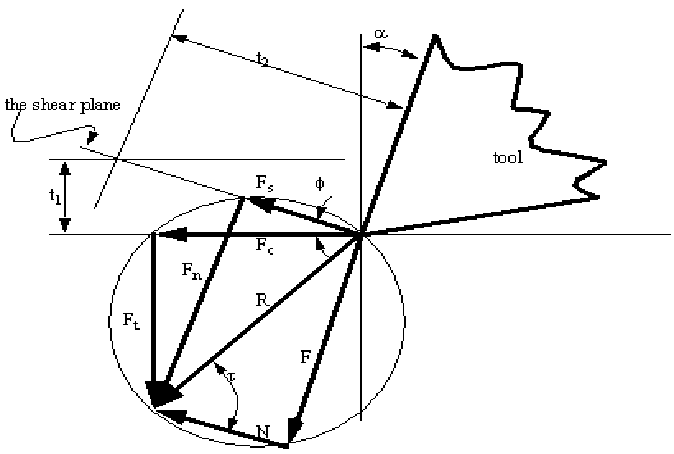


Fig 2.12 Merchant's Circle Diagram

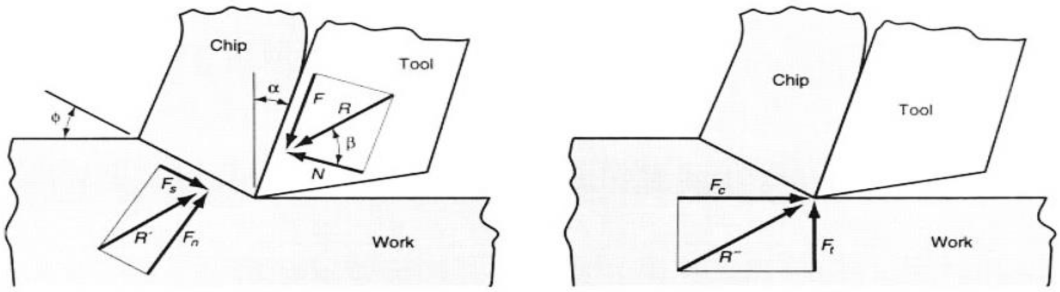


Fig 2.13.ForceRelationships (Source: on site 23rd January 2011)

F_S = shear force

F_n = force normal to shear plane

r = tool rake angle (positive as shown)

ϕ = shear angle

τ = frictional angle

Cutting Force and Thrust Force

- F, N, F_s, and F_n cannot be directly measured
- Forces acting on the tool that can be measured:
- Cutting force F_c and Thrust force F_t

Forces in Metal Cutting

- Equations can be derived to relate the forces that cannot be measured to the forces that can be measured:

$$F = F_c \sin\alpha + F_t \cos\alpha \quad (2.10)$$

$$N = F_c \cos\alpha - F_t \sin\alpha \quad (2.11)$$

$$F_s = F_c \cos\phi - F_t \sin\phi \quad (2.12)$$

$$F_n = F_c \sin\phi + F_t \cos\phi \quad (2.13)$$

Based on these calculated force, shear stress and coefficient of friction can be determined

Normal force at the rake face of tool (N)

Frictional Force along the rake face of the tool (F)

$$F = F_c \sin\alpha + F_t \cos\alpha \quad (2.14)$$

$$N = F_c \cos\alpha + F_t \sin\alpha \quad (2.15)$$

As the chip slides over the tool face under pressure therefore , the kinematic coefficient of friction may be expressed as :

Coefficient of friction between tool and chip:

$$\mu = \frac{F}{N} \tag{2.16}$$

$$\mu = \frac{Fc \sin\alpha + Ft \cos\alpha}{Fc \cos\alpha + Ft \sin\alpha} \tag{2.17}$$

Friction angle related to coefficient of friction as follows:

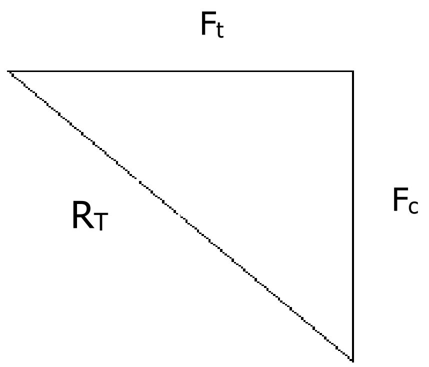
$$\mu = \tan\beta \tag{2.18}$$

2.12.1 Determination of the ResultantCutting Force

The resulting dynamic cutting force or the Effective cutting Force (R_T) is obtained from the register of the dynamical cutting forces by means of experimental testing. This register is a series of numerical data obtained through measurement of physical cutting forces.

- Vector addition of F and N = resultant R
- Vector addition of F_s and F_n = resultant R'
- Forces acting on the chip must be in balance:
    - R' must be equal in magnitude to R
    - R’ must be opposite in direction to R

R’ must be collinear with R



From Pythagoras theorems

$$R_T = \sqrt{F_t^2 + F_c^2} \qquad (2.19)$$

Cutting force control

- The cutting force value is primarily affected by:
- Cutting conditions (cutting speed V, feed f, depth of cut d)
- Cutting tool geometry (clearance and rake angle)
- Properties of work material the simplest way to control cutting forces is to change the cutting conditions.

2.12.2 Velocity relationship in orthogonal machining

Three velocities come into play when the tool cuts the material, these are as follows:

Cutting Velocity (V_C). Is the velocity of the cutting tool relative to the workpiece and is directed parallel to the compressive force on the shear plane this equals to the effective cutting speed

Chip velocity (V_f) Is the velocity of chip relative to the tool and parallel to the tool face.

Shear velocity (Vs) Is the velocity of the chip relative to the workpiece and is directed

V_f = Velocity of chip relative to tool $= \dfrac{VoSin\emptyset}{Cos(\alpha - \emptyset)}$ (2.20)

V_S = Velocity of chip relative to workpiece $= \dfrac{VoCos\alpha}{Cos(\alpha - \emptyset)}$ (2.21)

2.13. CHIP THICKNESS RATIO

In a machining process, a sharp tool cuts through some workpiece, generally by skimming along its surface. The "depth of cut" is the measurement of how far beneath the surface of the workpiece the tool is penetrating.

The “chip thickness" is the thickness of the material being cut awayone might think that the thickness of the removed material would be equal to the depth of cut, and sometimes it is. In that case, the chip thickness ratio is 1.0. However, depending on many other factors (cutting tool geometry, material properties, etc.), sometimes the chip will be thicker or thinner than the depth of cut, due to deformation of the chip as it is removed. This change of thickness as the chip material is being removed is defined as the "chip thickness ratio."

t_1	=	Depth of cut (chip thickness after cutting)
t_2	=	Chip thickness(Chip thickness before cutting)
$\propto$	=	Rake angle
$\emptyset$	=	shear angle
AB	=	shear plane

$$AB = \frac{BD}{Sin\emptyset} = \frac{BC}{Cos(\emptyset - \propto)} \quad (2.22)$$

$$= \frac{t_1}{Sin\emptyset} = \frac{t_2}{Cos(\emptyset - \propto)} \quad (2.23)$$

$$\frac{t_1}{t_2} = \frac{Sin\emptyset}{Cos(\emptyset - \propto)} = r_c \quad (2.24)$$

Simplifying Equation 2.24

$$\frac{t_1}{t_2} = \frac{Sin\emptyset}{Cos(\emptyset - \propto)} \quad (2.25)$$

$$\frac{sin\emptyset}{cos\emptyset \ cos\propto + sin\emptyset sin\propto} \quad (2.26)$$

$$\frac{\frac{\sin\emptyset}{\cos\emptyset}}{\frac{\cos\emptyset \ \cos\propto}{\cos\emptyset}} + \frac{\sin\emptyset\sin\propto}{\cos\emptyset} \quad (2.27)$$

Therefore

$$r_c = \frac{tan\,\emptyset}{cos\propto + tan\,\emptyset sin\propto} \quad (2.28)$$

$r_c$is known as chip thickness ratio and is always less than unity ($r_c < 1$).

2.14. DETERMINATION OF SHEAR PLANE ANGLE

Base on the geometric parameters of orthorgonalmodel , the shear plane angle ϕ can be determine as

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha} \quad (2.29)$$

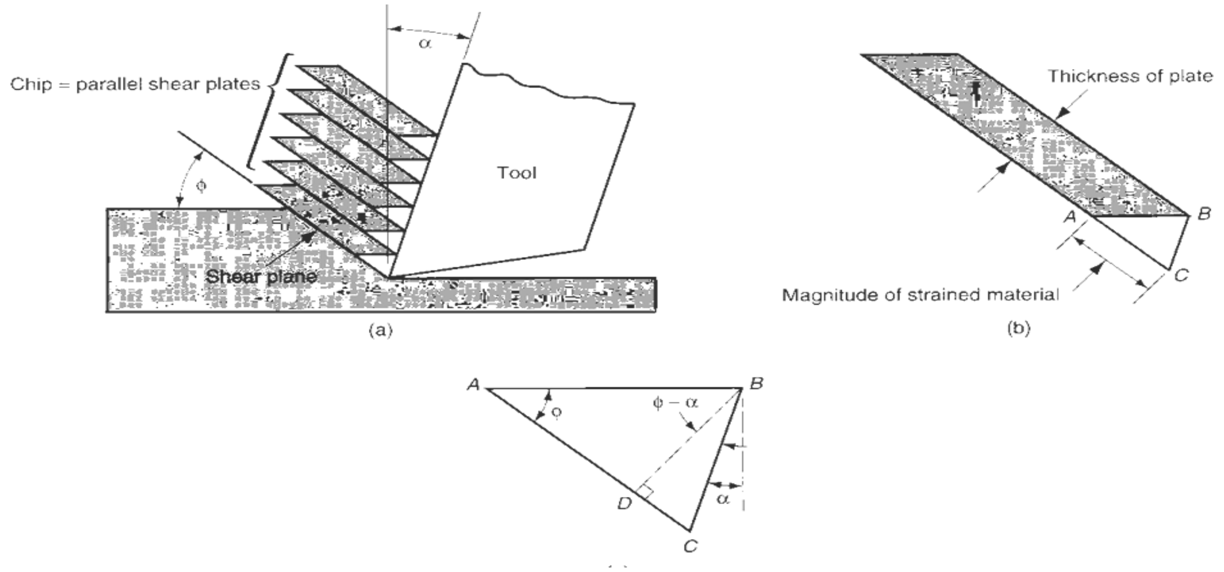


Fig 2.9 Shear strain during chip formation

(a) chip formation depicted as a series of parallel plates sliding relative to each other , (b) one of the plates isolated to show shear strain and (c) shear strain triangle used to derive strain equation (Source: Groover 2007)

CHAPTER THREE

3.0 MATERIALS AND METHODS

The research was carried out at Mechanical Engineering Department of University of Lagos. The machining was conducted using a Centre lathe machine in which turning operations were carefully carried out on the chosen workpiece material under the following machining variables, namely the cutting speed (V), feed (f),depth of cut (d) and tools of various geometries (rake angle α). A single point turning operation was selected for several reasons. First, it is a common industrial operation utilized by manufacturing concerns which must generate cylindrical shapes. Second, well defined economic models for single point turning have been developed and could be used in the analysis. Third, an engine lathe and the associated experimental equipment were available for use. Finally, experimental tooling costs would have been excessive if a drilling or milling operation, for example, was chosen.

3.1 MATERIALS

3.1.1 Workpiece Materials

Aluminium alloy was used as workpiece material, (50mm), aluminium alloys are among the most commonly used lightweight metallic materials as they offer a number of different interesting mechanical and thermal properties. In addition, they are relatively easy to shape metals, especially in material removal processes, such as machining. In fact, aluminum alloys as a class are considered as the family of materials offering the highest levels of machinability, as compared to other families of lightweight metals such as titanium and magnesium alloys. This machinability quantifies the machining performance, and may be defined for a specific application by various criteria, such as tool life, surface finish, chip evacuation, material removal rate and machine-tool power.

Table 3.1 Chemical Composition of WorkpieceMaterial.

Element:	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Composition:	≤ 0.8%	0.7%	≤ 0.4%	0.15 %	≤1.2 %	0.35 %	.25%	0.15%	95.8%

3.1.2 Cutting Tool Material

The tools selected were high speed steel. High speed steel as a cutting tool was used for the experiment because of its acceptability as a cutting tool material globally. When properly heat- treated, high speed steel has hardness in the range of Rockwell C 62 to C 65, and retains hardness at high temperature up to 500°C.Consequently high speed steel can be worked at substantially higher cutting speeds. HSS has high wear resistance due to the presence of tungsten, chromium and vanadium carbides in matrix.

Table 3.2 chemical composition of the cutting tool material

Element :	Iron	Cobalt	Carbon	Tungsten	Molybdenum	Chromium	Vanadium
Composition:	74.7%	8.0%	1.1%	1.5%	9.5%	4.0%	1.2%

3.13. Machining Equipment

Lathe Machine (LH35-N)

Tool and cutter grinder (Type NUA-25 NRFABR.772 Rok Budowy)

HSS Cutting tools with different rake angles of 18°,20°and 28°.

Workpiece: Seamless Aluminium 50 mm diameter

Measuring tools (vernier caliper, combination square and meter rule)

Tool post dynamometer (Type 60Mercer England)

3.1.4 Test Procedure.

The following procedures were followed in the course of the investigation; the workpiece was marked axially on the surface, so as to determine the length of the deformed chip. The diameter was measured, so as to obtain the circumference and the undeformed chip length. The workpiece was carefully mounted on the three jaw chuck of the lathe and the concentricity of the workpiece was checked using a dial indicatorand the cutting tool properly secured in position . The workpiece was checked for concentricity, and then faced to obtain a smooth surface with parallel faces.

The cutting tools were grounded to the desired geometry using a tool and cutter grinder.At the instance of cutting, the vertical and horizontal forces as observed on the dynamometer were taken. Also, the chips formed during each feed were collected and labeled for further analysis in the metrology laboratory. This was repeated for all the experiments, varying at the cutting parameters, in the metrology laboratory. The length and thickness of the various chips were measured and recorded to conclude the analysis required in this research.

The cutting experiments were carried out on a lathe machine (LH35-N) and machining was carried out on standard high speed steel tools with a 20 mm square shank. Experiments were done under different speeds in the ranges of: 71, 90, 119, m/min, depths of cut of 0.5, 1.0 and 1.5, mm and feed rate was 0.15, 0.20, 0.25 mm/rev. All tests carryout without the use of cutting fluid; and a dynamometer was used to determine the cutting forces exerted during the cutting operation (horizontal and vertical forces). The nominal (starting) workpiece diameter was 50 mm and 500mm long.

The dynamometer used for this series of tests was a two force component dynamometer (type mercer England serial No 154)manufactured by Tech equipment. The dynamometer essentially consisted of a cantilever structure which held the cutting tool. Each experiment was carried out with new sharp tools in order to keep the cutting conditions unchanged. The cutting-testswere conducted without coolant and, as a result, in total 27 experiments were performed. Deflection of the cantilever was measured by a dial gauge indicator as show in the experimental setup.

Three different types of tests were done to measure the cutting force on the cutting tool.

- The first test consisted of keeping the feed and depth of cut same and changing the velocity of the lathe. three different speeds were used for this test.
- The second test consists of varying the feed and keeping the velocity and depth of cut the same.three different feed rates are used for this test.
- The third test consists of varying the depth of cut while keeping the velocity and feed same. three different depth of cut are used for this test.

For each set data are acquired and documented in the table for further analysis.

Figure 3.1a Experimental Setup (Tool post dynamometer for measuring vertical and horizontal cutting forces)

Figure 3.1b Experimental Setupof tool post dynamometer and workpiece

3.1.5. Reading the Dynamometer

As shown above Type 60 Mercer dynamometer was used to measure the vertical and horizontal forces with the following factors;

Vertical calibration factor = 259kN/mm^2

Horizontal calibration factor = 268kN/mm^2

Multiplying factor of 0.002 for both forces

To obtain the actual vertical and horizontal forces, we multiply each of the observed readings from the dynamometer by the constants.

Observed reading × calibration factor × multiplying factor = actual cutting force

Cutting parameters, i.e. cutting speed, cutting depth and feed rate, were selected accordingly so that, the experimentally measured cutting force should not exceed the upper limit of the dynamometer working range. Cutting speed: V= 71, 90, 119, m/min,

• Feed rate: s= 0.15, 0.2, 0.25 mm/rev

• Depth of Cutting: = 0.5, 1.0, 1.5, mm

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

Table 4.1: Below shows Experimental Data and Cutting forces obtained from dynamometer reading .

Experiement Number	Speed V (m/mins)	Feedrate (mm/rev)	Depth of cut (mm)	Rake angle (o)	Resultant cutting ForceN
LBR 1	**90**	**0.15**	**1.0**	**28**	**116**
LBR 2	**119**	**0.25**	**1.0**	**20**	**162**
LBR 3	**90**	**0.2**	**0.5**	**28**	**69**
LBR 4	**90**	**0.15**	**0.5**	**20**	**63**
LBR 5	**119**	**0.2**	**1.0**	**18**	**173**
LBR 6	**119**	**0.2**	**0.5**	**20**	**62**
LBR 7	**90**	**0.2**	**0.5**	**18**	**101**
LBR 8	**90**	**0.25**	**1.0**	**28**	**145**
LBR 9	**71**	**0.2**	**1.5**	**20**	**323**
LBR 10	**71**	**0.2**	**1.0**	**18**	**207**
LBR 11	**90**	**0.15**	**1.0**	**18**	**159**
LBR 12	**90**	**0.25**	**0.5**	**20**	**100**
LBR 13	**119**	**0.2**	**1.5**	**20**	**240**
LBR 14	**90**	**0.25**	**1.5**	**20**	**265**
LBR 15	**90**	**0.25**	**1.0**	**18**	**244**
LBR 16	**119**	**0.15**	**1.0**	**20**	**116**
LBR 17	**119**	**0.2**	**1.0**	**28**	**153**
LBR 18	**71**	**0.15**	**1.0**	**20**	**192**
LBR 19	**90**	**0.15**	**1.5**	**20**	**224**
LBR 20	**90**	**0.2**	**1.0**	**20**	**184**
LBR 21	**90**	**0.2**	**1.5**	**28**	**216**
LBR 22	**90**	**0.2**	**1.5**	**18**	**280**
LBR 23	**71**	**0.2**	**0.5**	**20**	**104**
LBR 24	**90**	**0.2**	**1.0**	**20**	**183**
LBR 25	**71**	**0.2**	**1.0**	**28**	**156**
LBR 26	**90**	**0.2**	**1.0**	**20**	**184**
LBR 27	**71**	**0.25**	**1.0**	**20**	**189**

Table 4.2 below shows the Chip thickness ratiocomputed and Chip length obtained during the experiement.

Exp. Num	Speed V (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Rake angle (^{o})	Chip length (mm)	Chip thickness ratio(mm)
LBR 1	90	0.15	1.0	28	170mm	0.10 mm
LBR 2	119	0.25	1.0	20	152 mm	0.12 mm
LBR 3	90	0.2	0.5	28	163 mm	0.14 mm
LBR 4	90	0.15	0.5	20	161 mm	0.08 mm
LBR 5	119	0.2	1.0	18	155 mm	0.13 mm
LBR 6	119	0.2	0.5	20	156 mm	0.12mm
LBR 7	90	0.2	0.5	18	172 mm	0.15mm
LBR 8	90	0.25	1.0	28	146 mm	0.19 mm
LBR 9	71	0.2	1.5	20	148 mm	0.10mm
LBR10	71	0.2	1.0	18	165 mm	0.11mm
LBR11	90	0.15	1.0	18	147 mm	0.62mm
LBR12	90	0.25	0.5	20	132 mm	0.60mm
LBR13	119	0.2	1.5	20	180 mm	0.63mm
LBR14	90	0.25	1.5	20	150 mm	0.40mm
LBR15	90	0.25	1.0	18	153 mm	0.52mm
LBR16	119	0.15	1.0	20	130 mm	0.2mm
LBR17	119	0.2	1.0	28	160 mm	0.10mm
LBR18	71	0.15	1.0	20	150 mm	0.12mm
LBR19	90	0.15	1.5	20	153 mm	0.11mm
LBR20	90	0.2	1.0	20	130 mm	0.13mm
LBR21	90	0.2	1.5	28	160 mm	0.14mm
LBR22	90	0.2	1.5	18	163 mm	0.16mm
LBR23	71	0.2	0.5	20	132 mm	0.15mm
LBR24	90	0.2	1.0	20	136 mm	0.13mm
LBR25	71	0.2	1.0	28	136 mm	0.15mm
LBR26	90	0.2	1.0	20	135 mm	0.15mm
LBR27	71	0.25	1.0	20	146 mm	0.16mm

4.2. DISCUSSIONS

Table 4.1 above shows measured cutting force , it could be seen from the table that the cutting force in Newton differed with the different cutting conditions employed. The lowest cutting force (62 N) occurred at the cutting speed of 119 m/min, feed rate of 0.20mm, depth of cut of 0.5 mm and rake angle 20^o. At the cutting speed of 71 m/min, feed rate of 0.2 mm, Depth of cut of 1mm/rev. and rake angle of 18^o the highest cutting force of 323 N was recorded.

4.2.1. EFFECTS FEED RATE ON THE CUTTING FORCE

The results presentedin Table 4.1 show the evolution of cutting forces according to feed rate .if the feed rate increases section of the shered chip increases because the metal rupture more and requires large efforts for chip removal. Hence cutting force increases as feed rate increases.

The effect of the parameters on cutting force is very complex and it shows irregular behavior. Only one indication can be noted that the cutting force highly affected by feed rate and slightly by cutting speed (I.A. Choudhury, M.A. El-Baradie 1999 and K. Kadirgama and K.A. Abou-El-Hossein 2005). This shows that the feed rate is a dominant parameter and it plays a very important role on the cutting force.

The cutting force increased as the cutting speed and feed rate were increased. When the cutting speed is 71 m/mins and the feed rate was 0.15 mm/rev at constant depth of cut and rake angle of 1mm and 20^o respectively the cutting force was 165 N, the cutting force drastically increased to 322 N as the cutting speed and feed rate was increased to 119 m/mins and 0.25 mm/rev. respectively, as the depth of cut and rake angle remain the same. Such a drastic change illustrates the effects of cutting speed and feed rate in cutting force.

4.2.2 Effects of Depth of cut and on the Cutting force

A similar scenario occurred when cutting parameters such as depth of cut and rake angle were varied at constant cutting speed and feed rate.The results obtained as in Table 4.1 shows the evolution of cutting force according to Depth of cut . With increase in depth of cut the chip thickness becomes significant which causes the growth of volume deformed . Hence cutting force increases with increase in Depth of cut.

Gunay and Seker (2005), stated that the main cutting force was reduced by increasing the rake angle in positive direction and reducing the depth of cut. In other words, cutting force will increase as rake angle reduces in positive direction and depth of cut is increased.

It is clear from the Table 4.1 that as the depth of cut and rake angle were at 0.5 mm and 28^o, the cutting force was 101 N. the cutting force was increased to 197 N when the depth of cut and rake angle were adjusted to 1.5 and 18^o respectively at constant cutting speed and feed rate of 90 m/mins and 0.20. This shows that the depth of cut and rake angle plays a role in affecting the cutting forces.

4.2.3 EFFECT OF CUTTING SPEED ON CUTTING FORCE

The result from the experiements carried out indicates that , there is no much effect of cutting speed on cutting force . still increase in cutting speed generally leads to a reduction in cutting force. This is due to rise in the temperature in the cutting zonewhich makes the metal machined more plastic and consequently the effort necessary for machining decreases.

4.2.4 CHIP FORMATION AND CHIP SEGMENTATION

The chip shape and microstructure constitute a good indicator of the deformation havingoccurred during the machining process. The chip formation mode depends on the workpiece material, the tool geometry and the cutting conditions. A small and segmentedchip is preferable when cutting metals. Several research works have analyzed chipformation in order to identify the optimal conditions for improving machining andmachinability. Xie et al (1996) developed a coefficient identifying chip segmentation, called the flow localization parameter. Several tests were carried out in the laboratory in order to characterize the chip shape during the machining of aluminum alloys. Table 4.2 presents the chip thickness ratio and chip length obtained during the machining process.It is observed in (Annex) that, the chip is generally continuous for, the chip length decreases as thecutting speed increases; this decrease in thelength of the chip depends not only on the cutting speed, but also on the feed rate. Equally the chip length depends not only on the material properties (ductility andBrittleness for example) but also on the cutting conditions.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research work was undertaken to is of investigate the effect of cutting parameters on the cutting force in turning of Aluminium with HSS tool.

1. The experimental results show that the cutting force and feed force are low at high cutting speed and comparatively high at low cutting speed. This is because as cutting speed increases the chips are thinner and shear angle increases thus decreasing chip reduction coefficient and chip strains. That means the plastic deformation of metal takes place with less strain because of greater shear angle, the force and power consumption being low. At higher cutting speeds, BUE formation disappears and chip-tool contact length decreases resulting in the reduction of cutting force.
2. The experimental results show that the cutting force are low at low feed and depth of cut and comparatively high at high feed and high depth of cut. The greater the feed and depth of cut , larger the cross sectional area of the uncut chip, the volume of the deformed metal and consequently the greater is the resistance of the material to chip formation and larger is the force P_z will be in turning operation.
3. Feed is the most significant variable affecting cutting force followed by depth of cut and cutting speed. The interaction of feed and depth of cut is the next influencing factor on the cutting force

5.2 Recommendations

1. Based on the investigation that carried out , several recommendations for further work can be made. These are:
2. The information obtained from different experiments can be used to generate a cutting force model , that can be used to predict cutting forces.
3. This experiment should be repeated with different machine and conditions to verify the uniformity of the data obtained.
4. Study on the performance of other tools and material on turning be carried out to provide wide variety of data for the purpose of tool design and manufacture.
5. Further studies can be carried out by using different materials so to make comparism of cutting forces.
6. The data obtained from the experiments can be used further for the power and energy efficiency calculations.