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THE STUDY OF THE AGGRESSIVE TURNING PROCESS ON ALUMINIUM FOR AUTOMOTIVE APPLICATIONS

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This report is presented as partial requirement for the completion of the Bachelor of Mechanical Engineering (Thermal Fluid) Degree Programme

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MAY 2009

"I hereby, declare this thesis is result of my own research except for summary and quotes that cited in the references"

Signature	: ………………………
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To my beloved family

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Lastly, I would like to thank my family throughout the efforts of this report be in the form of encouragement or advice.

ABSTRAK

Kajian proses melarik kelajuan tinggi pada aluminium untuk aplikasi-aplikasi automotif adalah satu usaha untuk memahami konsep memesin pada kelajuan tinggi yang kini tersebar secara meluas dalam pelbagai industri pembuatan terutama dalam industri automotif. Objektif-objektif penyelidikan ini adalah untuk mengkaji tentang kebaikan dan cabaran proses melarik kelajuan tinggi pada aluminium dan untuk menakrifkan parameter proses melarik kelajuan tinggi yang terkawal. Dalam kajian ini, keberkesanan kaedah DOE yang diamalkan dalam proses melarik kelajuan tinggi akan ditumpukan. Kerja-kerja analisis adalah tertumpu pada keberkesanan kelajuan *spindle*, kadar huluran dan kedalaman pemotongan pada aluminium. Tambahan pula, cabaran-cabaran dalam proses melarik kelajuan tinggi seperti kehausan mata alat dan penghasilan serpihan logam akan dikaji. Oleh itu, parameter proses melarik kelajuan tinggi yang terkawal dapat ditakrifkan. Keutamaan kajian ini adalah untuk menyediakan data yang penting untuk memperbaiki kadar pengeluaran dan membantu industri untuk mejimatkan masa dan kos.

ABSTRACT

The study of the aggressive turning process on aluminium for automotive applications is an effort to understand the high speed machining concept which now widely spread in variety of manufacturing industry especially in automotive industry. The goals of this investigation are to study the potential benefits and challenges of the aggressive turning process on aluminium and to define the aggressive turning control parameter. The study will focus on the effectiveness of the aggressive turning practice by DOE method. The analytical work is towards the effect of spindle speed, feed rate and depth of cut on the aluminium. Moreover, the challenges of aggressive turning such as tool wear and chip formation will be investigated. Thus, the aggressive turning control parameters can be defined. The particular strength of this study is to provide significant data in order to improve production rate and help the industry to save time and cost.

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LIST OF SYMBOLS

<u>Concise list of symbols in order of appearance:</u>

ρ	= density of metal
E	= modulus of elasticity
s	= tensile strength
E/ρ	= specific stiffness
s/ρ	= specific strength
v	= cutting speed of the workpiece
D	= initial diameter of the workpiece
n	= spindle speed of the workpiece
f	= rate of feed in mm/min
S	= tool feed in mm/rev
t	= depth of cut
d	= diameter of the machined surface
k	= levels of experiment

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Turning is one of the main types of machining where material is removed using a cutting tool. It allows rotating parts to be produced using a single-edge cutting tool. The cutting tool is set at a certain depth of cut (mm or inch) and travels to the left with a certain velocity as the workpiece rotates (Kalpakjian and Schmid 2006).

High speed machining (HSM) was first develop by German inventor during year 1920 and now widely spread in variety of manufacturing industry included aerospace and automotive sectors where to produce high precession and accuracy parts. Major advantages of high speed machining are high material removing rate, reduction of lead time and the most important is increase parts precision and surface finish. Nowadays, many industries facing challenge to improve the quality of products and processes with minimum cost and time constraints. One obvious benefit of HSM in general is that at high spindle speed the feed can be increased proportionally with the same chip-load as in conventional machining (Hamade and Ismail 2005).

The preferred speed is determined based on the material being cut. Excessive spindle speed will cause premature tool wear, breakages, and can cause tool chatter, all of which can lead to potentially dangerous conditions. Using the correct spindle speed for the material and tools will greatly affect tool life and the quality of the surface finish. Feed rate is the velocity at which the cutter is advanced against the workpiece. When deciding what feed rate to use for a certain cutting operation, the calculation is fairly straight forward for single-point cutting tools. The ratio of the spindle speed and the feed rate controls how aggressive the cut is, and the nature of the chips formed. Depth of cut is defined as the thickness of material removed from a workpiece in a single machining part (Davis 1998). General machine practice is to use a depth of cut up to five times the rate of feed. If chatter or machine noise develops, the depth of cut will be reduced.

From a material point of view, aluminium is a soft metal that has the face-centered cubic (FCC) unit cell structure, which is one reason why aluminium is an easy-to-machine metal with machinability ratings superior to those of most engineering metals. This same property makes aluminium a metal that lends itself easily to high-speed machining in general (Hamade and Ismail 2005).

1.2 Problem Statement

Currently, there has yet to be any comprehensive study on the aggressive turning on aluminium for automotive applications. No any significant data showing how aggressively and effectively aluminium can be turned. Providing such data can help users to improve the turning process on aluminium.

1.3 Objectives

- To study the potential benefits and challenges of the Aggressive Turning process on aluminium
- To define the Aggressive Turning Control Parameter

1.4 Scope

The study will focus on the effectiveness of the aggressive turning practice by DOE method. The Okuma Space Turn LB 200-R CNC lathe machine will be used in the experiment. The conditions of the aluminium after been aggressive turned will be analyzed by using visual inspection method.

1.5 Importance of Study

The aggressive turning of aluminium by controlling the parameters could help the automotive industry to improve production rate and increase the challenges in the global markets. Besides, DOE method could help the industry to save time and cost.

1.6 Expected Results

The production rate can be increased by controlling the main parameters such as spindle speed, feed rate, and also depth of cut. The challenges of aggressive turning process such as tool wear and chip formation were also studied. Besides, by applying DOE method on this experiment, the aggressive turning control parameters can be defined to produce the best aggressive turning process.

CHAPTER 2

LITERATURE REVIEW

2.1 Aluminium

According to Hamade and Ismail (2005), Aluminium is a soft, low density *(ρ)* metal that appeals to weight sensitive industries because of its competitive specific stiffness *(E/ρ)* and strength *(s/ρ)* where *E* is the modulus of elasticity and s is the tensile strength. Aluminium in pure form is not very useful for forming into structural material. Almost all aluminum used for aircraft parts or car parts or other structures is an alloy. With 2,700 kg/m3, the density of aluminium is one third of that of steel. Aluminium allows a saving of up to 50% of weight over competing materials in many applications.

2.2 Aluminium for Automotive Applications

Aluminium is most likely to play a more important role in future car generations. Car bodies contribute 25% to the total weight of a car.

Table 2.1: Properties of steel and aluminium (Source: Carle and Blount, 1999)

	Steel	Aluminium alloy (AlMgSi)
Module of elasticity in N/mm^2	190,000 - 220,000	60,000 - 80,000
Strength N/mm^2	290 - 470	260 - 350
Density in kg/dm^3	7.85	2.7

From the table 2.1, the strength of aluminium sheet panels and extruded sections is approximately the same as that of steel body distortion or a break of the panel the same force must be applied. However, the rigidity of aluminium is lower than that of steel. That is partly due to the modulus of elasticity of aluminium that is just one-third that of steel (Carle and Blount 1999).

The average mass of passenger cars has dramatically increased since the 1970's and due to vehicle weight directly impacts fuel consumption, light-weighting is necessary more than ever to reduce CO2 emissions per km at the exhaust pipe. Typical relative and average absolute weight savings of today's main aluminium applications in mass-produced cars are given below (European Aluminium Association, 2007).

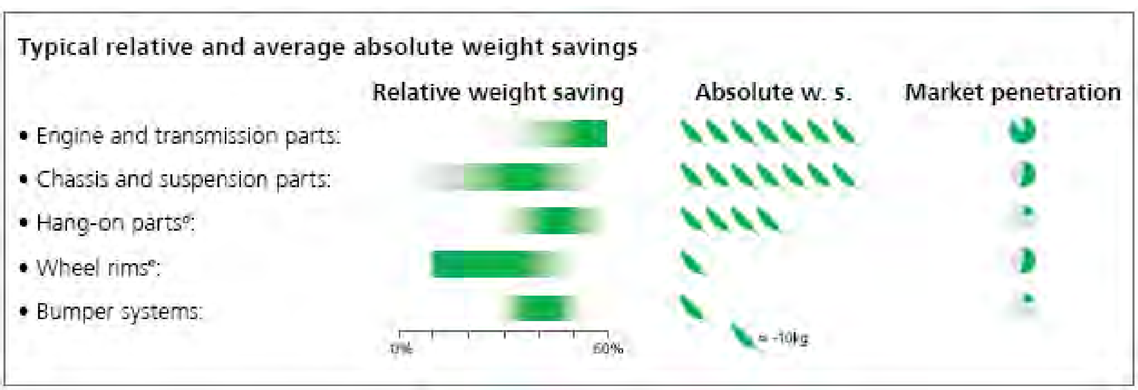


Figure 2.1: Typical relative and average absolute weight savings of aluminium (Source: European Aluminium Association, 2007)

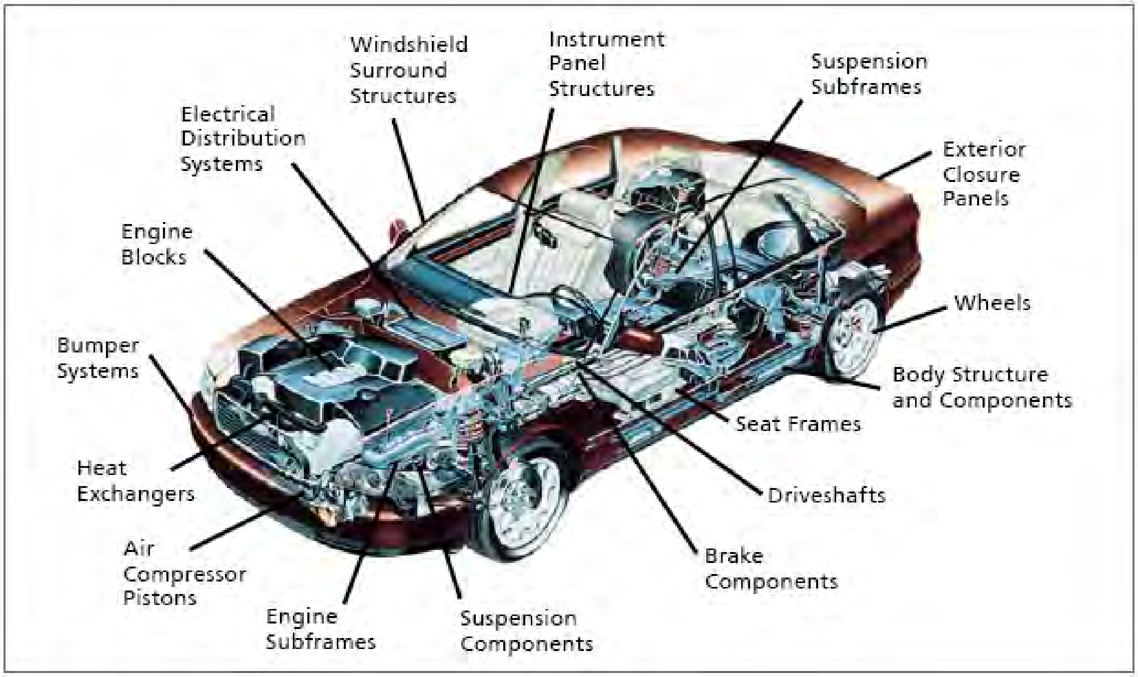


Figure 2.2: Aluminium applications in a car

(Source: European Aluminium Association, 2007)

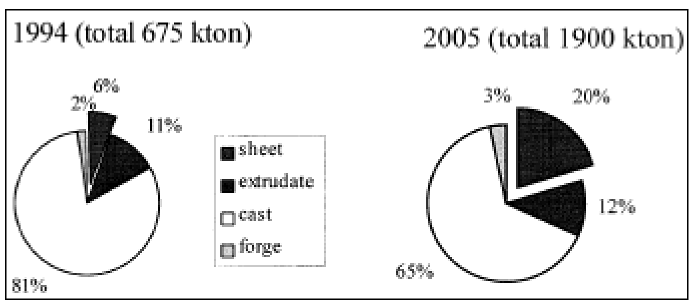


Figure 2.3: Development of aluminium consumption for automotive application in Europe (Source: Bassi et al., 1999)

As shown in Figure 2.3, a significant increase in sheet aluminium for automotive applications is expected. Recent examples of aluminium applications in vehicles cover power trains, chassis, body structure and air conditioning. As a key trend, the material for engine blocks, which is one of the heavier parts, is being switched from cast iron to aluminium resulting in significant weight reduction. As indicated in Figure 2.3, aluminium castings find the most widespread use in automobile. In automotive power train, aluminium castings have been used for almost 100% of pistons, about 75% of cylinder heads, 85% of intake manifolds and transmission (other parts-rear axle, differential housings and drive shafts etc.) For chassis applications, aluminium castings are used for about 40% of wheels, and for brackets, brake components, suspension (control arms, supports), steering components (air bag supports, steering shafts, knuckles, housings, wheels) and instrument panels.

Aluminium alloys have also found extensive application in heat exchangers. The market share of aluminium has grown steadily over the last 25 years and is now the material of choice for use in the automotive heat exchanger industry. Modern, high performance automobiles have many individual heat exchangers, e.g. engine and transmission cooling, charge air coolers (CACs), climate control (Miller et al. 2000).

2.3 Aluminium Alloys

Aluminium alloys are alloys of aluminium, often with copper, zinc, manganese, silicon, or magnesium to impart desired properties, such as strength, toughness, ductility, formability, weldability and corrosion resistance. They are much lighter and more corrosion resistant than plain carbon steel, but not quite as corrosion resistant as pure aluminium. Aluminium alloys with a wide range of properties are used in engineering structures. Alloy systems are classified by a number system (ANSI) or by names indicating their main alloying constituents (DIN and ISO).

Table 2.2: Manufacturing properties and typical applications of selected wrought aluminium alloys (Source: Kalpakjian and Schmid, 2006)

Alloy	Characteristics			Typical Applications
	Corrosion resistance	Machinability	Weldability	
1100	A	C-D	A	Sheet metal work, spun hollowware, tin stock
2024	C	B-C	B-C	Truck wheels, screw machine products, aircraft structures
3003	A	C-D	A	Cooking utensils, chemical equipment, pressure vessels, sheet metal work, builders' hardware, storage tanks
5052	A	C-D	A	Sheet metal work, hydraulic tubes, and appliances; bus, truck and marine uses
6061	B	C-D	A	Heavy duty structures where corrosion resistance is needed; truck and marine structures, railroad cars, furniture, pipelines, bridge railings, hydraulic tubing
7075	C	B-D	D	Aircraft and other structures, keys, hydraulic fittings

*A = excellent; D = poor.

Davis (1998) stated that most aluminium alloys can be machined at very high speeds because tool life is not an important consideration or limitation. However, the high-silicon alloys such as 380 (8.5% Si) and 390 (17% Si) are exceptions. According to the theories of metallurgical thermodynamics alloying elements can enter the crystal structure as solid solution or build various constituent phases depending on composition, temperature and on the kinetics of nucleation and growth processes. The types of phases existing in an alloy of given composition and at various temperature regimes are mapped in phase diagrams. The parameters of the complete chain of thermo-mechanical processes in the production of a cast or wrought product influence the type and distribution of alloying elements and constituent phases in the microstructure and thereby determine the properties and behaviour of the product. (Aluminium Automotive Manual 2008)

The specific properties of aluminum alloys must be considered (ESPI metals 2008):

- Their density allows high speeds of rotation and translation as the inertia of aluminum alloy chip is less than that of steel.
- Their modulus of elasticity, which is one third that of steel, requires appropriate chucking and clamping arrangements that avoid deformation and distortion. The alloy’s thermal conductivity assists with heat dissipation.
- Given the high rate of chip removal, the heat generated by the machining process is taken away with the chip without having the time to diffuse into the metal.
- A coefficient of linear expansion that is twice that of steel makes heating undesirable if criteria of dimensional stability are to be satisfied. Unlike steel, there is no need to provide heat treatment of the “stress-free annealing” type during machining.

2.4 Turning

El-Hofy (2007) studied that turning is a method of machining by cutting in which the workpiece carries out the main rotary motion while the tool performs the linear motion. The process is used for the external and internal turning of surfaces. The basic motions of the turning process are

1. The primary motion is the rotary motion of the workpiece around the turning axis.
2. The auxiliary motion is the linear motion of tool, also called the feed motion.

Table 2.3: Various turning process according to the direction of tool feed (Source: El-Hofy 2007)

Types of turning process	Direction of tool feed
Straight turning	Parallel to the turning axis
Taper turning	Intersects with the turning axis
Traverse turning	Perpendicular to the turning axis

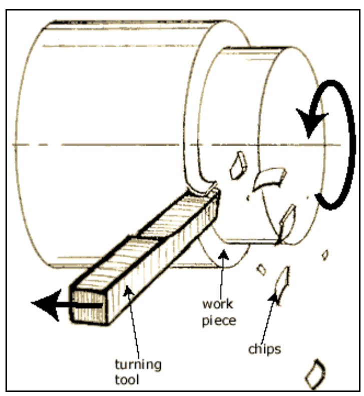


Figure 2.4: Schematic diagram of turning process (Source: www.efunda.com)

Facing is part of the traverse turning process. The term “facing” is used to describe removal of material from the flat end of a cylindrical part, as shown below. Facing is often used to improve the finish of surfaces that have been parted.

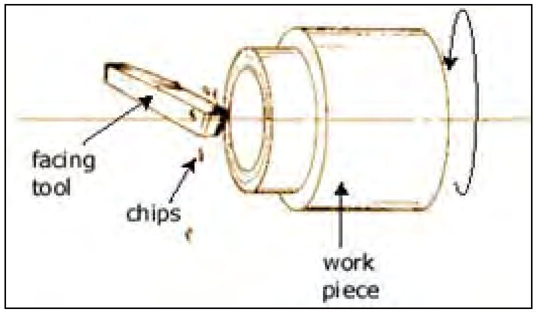


Figure 2.5: Schematic diagram of facing process (Source: www.efunda.com)

2.5 Single-point Cutting Tool

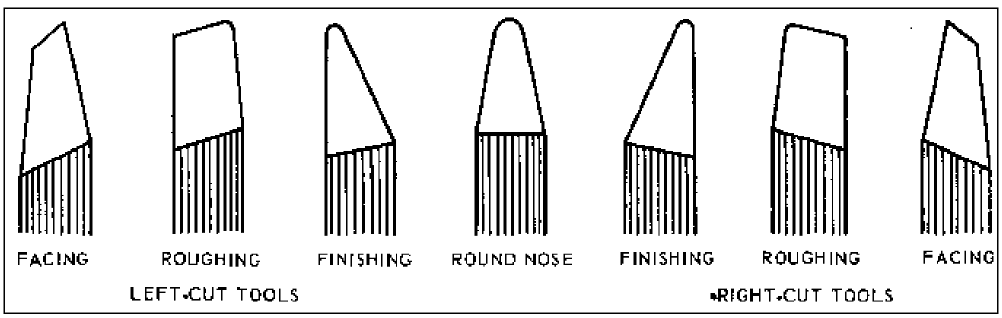


Figure 2.6: Standard cutting tools (Source: www.nmis.org)

A single point cutter bit is a tool that has only one cutting action proceeding at a time.Single-point lathe tools can be used in various ways:

- Facing tools are ground to provide clearance with a center.
- Roughing tools have a small side relief angle to leave more material to support the cutting edge during deep cuts.
- Finishing tools have a more rounded nose to provide a finer finish. Round nose tools are for lighter turning. They have no back or side rake to permit cutting in either direction.

The cutting edge is ground to suit a particular machining operation and may be resharpened or reshaped as needed. A radius ground onto the nose of the tool bit can help strengthen the tool bit and provide for a smooth cutting action. The ground tool bit is held rigidly by a tool holder while it is cutting.

The overall shape of the lathe tool bits can be rounded, squared, or another shape as long as the proper angles are included. Tool bits are identified by the function they perform, such as turning or facing. They can also be identified as roughing tools or finishing tools.

2.6 Tungsten Carbide Inserts

Carbide inserts can be square, triangular, round, diamond or other shapes. The strength of the cutting edge of an insert depends on its shape. The smaller the included angle, the strength of the edge is lower. In order to improve edge strength and prevent chipping, all insert edges usually are honed, chamfered, or produced with a negative land. Most inserts are honed to a radius of about 0.025mm (Kalpakjian and Schmid 2006).

Tungsten carbide is one of the major groups of carbides used for machining. Tungsten carbide and cutting tool inserts are commonly used in high-speed production work when heavy cuts are necessary and where exceptionally hard and tough materials are encountered. The inserts are designed to be indexed or rotated as each cutting edge gets dull and then discarded. Cutting tool inserts are not intended for reuse after sharpening. Because carbide is expensive and difficult to work with, typically the body of the cutting tool is made of steel, and a small cutting edge made of the harder material is attached. The cutting edge is usually either screwed on (insert), or brazed on to a steel shank.

2.7 Aggressive Turning / High Speed Turning

Aggressive turning or high speed turning is one of the processes of high speed machining. High speed machining (HSM) or high speed cutting (HSC), for a given material, is defined as the cutting speed above which shear localization develops completely in the primary shear zone. One suggestion is that 600 to 1800 m / min should be termed as high speed machining, 1800 to 18000 m / min very high speed machining, and greater than 18000 m / min as ultrahigh speed machining. High speed machining finds many industrial applications due to the development of tougher, more refractory tool materials and of high speed machining spindles. HSM can be used to machine parts that require the removal of significant amounts of material and to machine long, thin webs (El-Hofy 2007).

However, in comparison with high-speed milling and grinding, high-speed turning has not been widely applied in batch production. The main reason for this lies in the relatively short continuous cutting time, and lack of a workpiece clamping system that is safe and flexible at high rotational speeds (Feng et al. 2008).

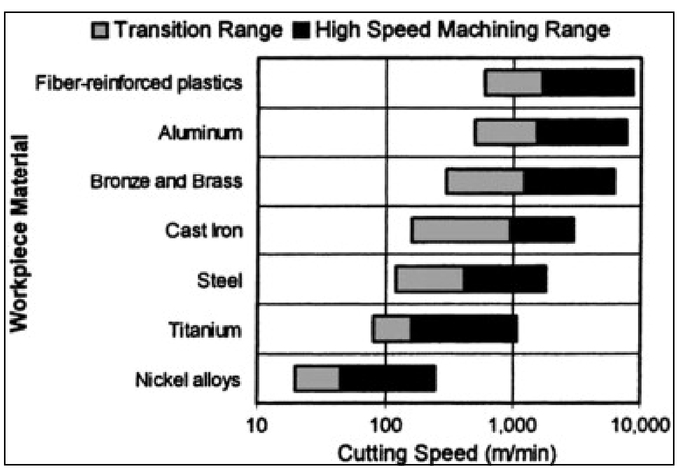


Figure 2.7: High speed cutting ranges in machining of various materials
(Source: Schulz and Moriwaki, 1992)

Major advantages of high speed machining are reported as: high material removal rates, the reduction in lead times, low cutting forces, dissipation of heat with chip removal resulting in decrease in workpiece distortion and increase part precision and surface finish. High speed turning is being used to reduce lead-times and manufacturing costs. The high speed turning is recognized as a main manufacturing technology for higher productivity and throughput (Schulz and Moriwaki 1992).

The study from Vaughn (1958) showed a series of variables involved in the traditional machining that became very important in HSM. Accordingly, the rate at which the metal can be machined is affected by:

- Size and type of the machine
- Cutting tool used
- Power available
- Material to be cut
- Speed, feed, and depth of cut

2.8 Spindle Speed, Feed Rate and Depth of Cut

The speed of the cutting motion or the peripheral speed of the workpiece is calculated in m/min (Youssef 2008):

$$v = \frac{\pi D n}{1000}\ \text{m/min}$$

Where D = initial diameter of the workpiece (mm), n = spindle speed of the workpiece (rpm). Therefore, the spindle speed is obtained by following this equation:

$$n = \frac{1000v}{\pi D}\ \text{rpm}$$

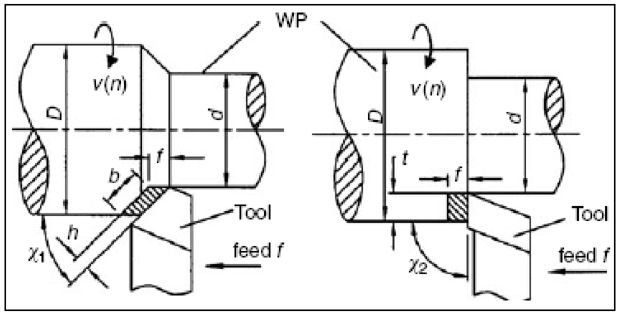


Figure 2.8: Basic machining parameters in turning (Source: Youssef, 2008)

The feed or feed rate is the distance the tool travels horizontally per unit revolution of the workpiece (mm/rev). The rate of feed *f* in mm/min is expressed by

$$f = SN$$

Where *S* is the tool feed in mm per revolution (El-Hofy 2007).

Depth of cut is the thickness of material removed in a machining operation. Depth of cut *t*, which is measured in a direction perpendicular to the workpiece axis, for one turning pass.

$$t = \frac{D - d}{2} \text{ mm}$$

Where *d* is the diameter of the machined surface (Youssef 2008).

2.9 Tool Wear

Tool wear is a significant problem in cutting. It is defined as a gradual deterioration of tools. For cutting tools, the following ones are the most frequent occurred. Two types of wear include:

- **Flank wear** in which the portion of the tool in contact with the finished part erodes.

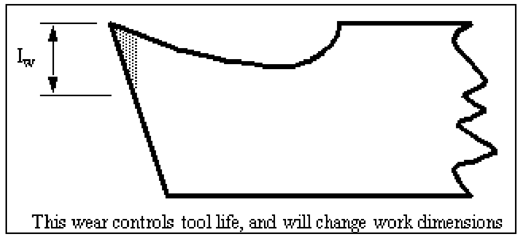


Figure 2.9: Flank wear (Source: www.eod.gvsu.edu)

- **Crater wear** in which contact with chips erodes the rake face. This is somewhat normal for tool wear, and does not seriously degrade the use of a tool until it becomes serious enough to cause a cutting edge failure.

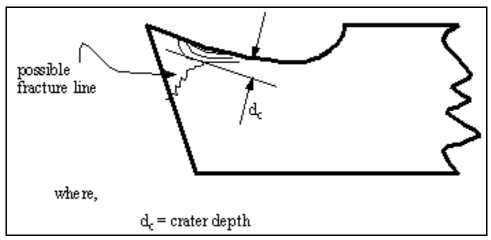


Figure 2.10: Crater wear (Source: www.eod.gvsu.edu)

Tool wear will increase cutting forces and cutting temperatures. It also decreased accuracy of finished part and a poor surface finish will be obtained. Reduction in tool wear can be accomplished by using lubricants and coolants while machining.

2.10 Chip Formation

The type of chips produced during machining depends on the material being machined, the tool and the cutting conditions at the time. These conditions include the rate of cutting condition of the machine and the use or absence of a cutting fluid. The mechanism of chip formation and separation is due to the extreme strain rate that occurs during the machining process. For all types of machining, including grinding, honing, lapping, turning, or milling, the phenomenon of chip formation is similar at the point where the tool meets the work. During the machining process three basic types of chips are formed:

Continuous Chip

This leaves the tool as a long ribbon and is common when cutting most ductile materials such as mild steel, copper and aluminium. It is associated with good tool angles, correct speeds and feeds, and the use of cutting fluid.

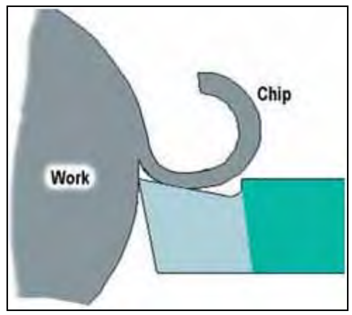


Figure 2.11: Continuous chip (Source: mmu.ic.polyu.edu.hk)

Discontinuous Chip

The chip leaves the tool as small segments of metal resulted from cutting brittle metals such as cast iron and cast brass with tools having small rake angles.

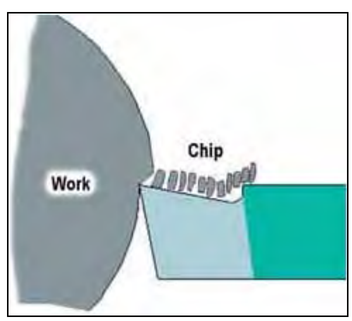


Figure 2.12: Discontinuous chip (Source: mmu.ic.polyu.edu.hk)

Continuous Chip with Built-up Edge (BUE)

This is a chip to be avoided and is caused by small particles from the workpiece becoming welded to the tool face under high pressure and heat. The phenomenon results in a poor finish and damage to the tool. It can be minimized or prevented by using light cuts at higher speeds with an appropriate cutting lubricant.

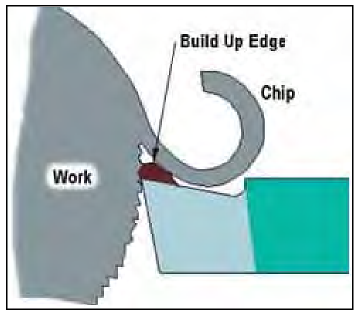


Figure 2.13: Continuous chip with built-up edge (Source: mmu.ic.polyu.edu.hk)

2.11 Cutting Fluids

Cutting fluids play a significant role in machining operations and impact shop productivity, tool life and quality of work. The primary function of cutting fluid is temperature control through cooling and lubrication (Aronson et al. 1994). A fluid's cooling and lubrication properties are critical in decreasing tool wear and extending tool life. Cooling and lubrication are also important in achieving the desired size, finish and shape of the workpiece (Sluhan 1994). A secondary function of cutting fluid is to flush away chips and metal fines from the tool / workpiece interface to prevent a finished surface from becoming marred and also to reduce the occurrence of built-up edge (BUE). Practically all cutting fluids presently in use fall into one of four categories:

- Straight oils
- Soluble oils
- Semisynthetic fluids
- Synthetic fluids

2.12 Design of Experiments

Design of Experiments (DOE) refers to experimental methods used to quantify indeterminate measurements of factors and interactions between factors statistically through observance of forced changes made methodically as directed by mathematically systematic tables. It is one of the many problem-solving quality tools that can be used for various investigations such as finding the significant factors in a process, the effect of each factor on the outcome, the variance in the process, troubleshooting the machine problems, screening the parameters, and modelling the processes. By using strategically designed and statistically performed experiments, it is possible to study the effect of several variables at one time, and to study inter-relationships and interactions (Konda et al. 1999).

A full factorial designed experiment consists of all possible combinations of levels for all factors. A full factorial experiment assists experimenters to study all possible combinations of the levels of the factors or process parameters in the experiment. By performing a full factorial experiment, one may be able to study the joint effects of two factors (or interactions) on a response by simultaneously changing the levels of factors. One of the major limitations of full factorial designs is that the size of the experiment is a function of the number of factors considered and to be studied for the experiment. (Antony 2003)

The strategy that used in designing, performing, and analyzing experiments is shown below:

- *Step 1* - Identify the potential factors by brainstorming a cause and effect design diagram.
- *Step 2* - Choose the factors for the study.
- *Step 3* - Select the appropriate working range for each potential factor considered in Step 2.
- *Step 4* - Select the experimental levels for each factor from within the extremes explored in Step 3.

• *Step 5* - If possible, trial run or dry run the experiments with all possible combinations within the range of each factor selected in an extremely short run to guard against a process failure owing to interactions.

• *Step 6* - Choose an orthogonal array for experiments or any experimental design (full factorial or fractional factorial).

• *Step 7* - Run experiments as designed. Experiments must be performed randomly.

• *Step 8* - Analyze the experimental results for the objective of the project. Draw conclusions and verify them with the objective evidence.

• *Step 9* - After step 8, if the results do not seem to be meeting the objective of the study, it could be owing to inappropriate factors considered in the study. Two choices are available: those are either start the experimentation all over with different factors, or the part design or processes design needs to be modified. Additionally, one could potentially use a different technique using the knowledge gained in steps 1 through 8 to achieve the goals set for the project.

CHAPTER 3

METHODOLOGY

3.1 Flow Chart

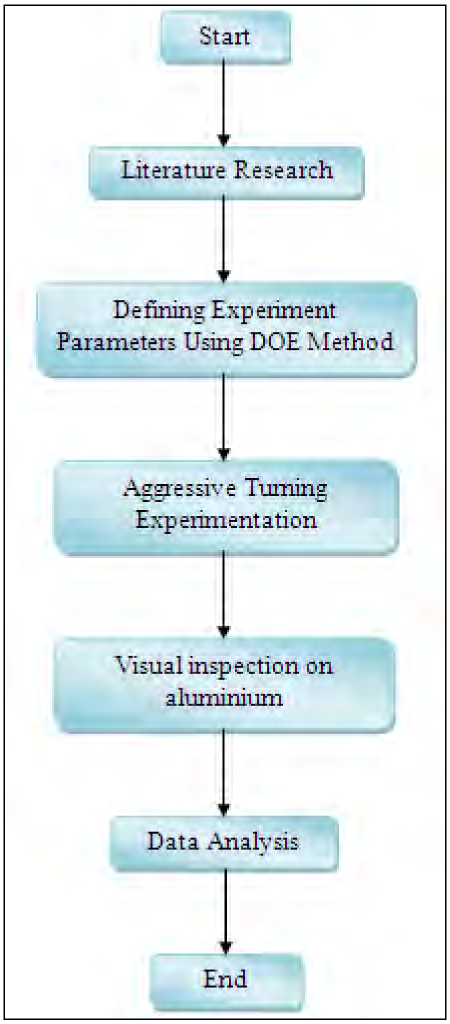


Figure 3.1: Flow chart of the methodology of aggressive turning on aluminium

In order to systematically satisfy the research objectives, the research methodology was applied and can be mainly divided in 4 major divisions:

3.2 Literature Research

At this initial stage, basic information regarding aggressive turning was obtained. In addition to that, supplementary research regarding the materials and tools required to successfully run the experiment and achieve the objectives were conducted. These include journal research on aggressive turning of aluminium; the study of tool wear and chip formation; and other directly or indirectly issue that would contribute to the success of the experiment.

3.3 Defining Experiment Parameters Using DOE Method

For this experiment, aluminium rod was selected as workpiece. The diameter and the length of the common used aluminium rod were set as 25.4 mm (1 inch) and 150 mm because this is the regular applications that practice in CNC workshop. Besides that, repetitive turning and facing process on one aluminium rod were also taking into consideration.

Figure 3.2: The aluminium rod that used in CNC lathe machine

In this present work, a 3^k factorial design has been used for developing the non-linear mathematical model with three levels (k=3) so that all interactions between the process parameters could be investigated effectively. The three input process parameters considered were spindle speed, feed rate and depth of cut. The diameter was not treated as an input process parameter in the design of experiments as it changes in each pass with the depth of cut. The three levels for each factor were chosen on the basis of data given in machining books, machine capabilities and workshop practice.

According to El-Hofy (2007), the cutting speed v for high speed machining is 600 to 1800 m/min. By using the equation below, the spindle speed range, n for high speed machining can be obtained:

$$n = \frac{1000v}{\pi D} \text{ rpm}$$

For v = 600 m/min,

n = 1000 (600m/min) / π (25.4 mm)

= 7519 rpm

For v = 1800 m/min,

n = 1000 (1800m/min) / π (25.4 mm)

= 22557 rpm

Therefore, the spindle speed of high speed machining is around 7519 – 22557 rpm. According to Kalpakjian (1997), the depths of cut are generally in the range of 0.5 – 12 mm while feed rate is usually in the range of 0.15 – 1 mm/rev. A total number of 27 experiments (3^3) runs have planned to be carried out within the following selecting range of input process parameters for turning process and facing process respectively:

- Spindle speed: 10000 – 20000 rpm
- Feed Rate: 0.15 – 1.0 mm/rev
- Depth of cut: 0.5 – 12.0 mm

Table 3.1: Theoretical process parameters of the design of experiments

Process Parameters	Low level	Medium level	High level
Spindle Speed, *n* (rpm)	10000	15000	20000
Feed Rate, *f* (mm/rev)	0.15	0.5	1.0
Depth of Cut, *t* (mm)	0.5	5.0	12.0

During the initial stage of implementation of the design of experiments, the input process parameters has been changed after refer the machine's specification, general practice used in workshop and statement from journal. The maximum spindle speed for Okuma Space Turn LB 200-R CNC lathe machine is 6000 rpm. The machine only runs up to 3000 rpm in machine workshop, Fasa B due to the consideration of chatter vibration and possibilities of machine breakdown. Besides that, according to Padmanabhan et al. (2008), the range of depth of cut used in CNC turning is 0.5 – 1.0 mm. The feed rate used is generally less than 0.1 mm/rev for spindle speed range from 1200 rpm to 1500 rpm. Feed rate of 1.0 mm/rev and depth of cut of 12.0 mm are considered too high. Therefore, the process parameters have been revised as in Table 3.2 after compare the statement of Kalpakjian and Padmanabhan.

Table 3.2: Actual process parameters of the design of experiments

Process Parameters	Low level	Medium level	High level
Spindle Speed, *n* (rpm)	1000	2000	3000
Feed Rate, *f* (mm/rev)	0.15	0.3	0.5
Depth of Cut, *t* (mm)	0.5	1.0	1.5

3.4 Aggressive Turning Experimentation

3.4.1 Experimental Design

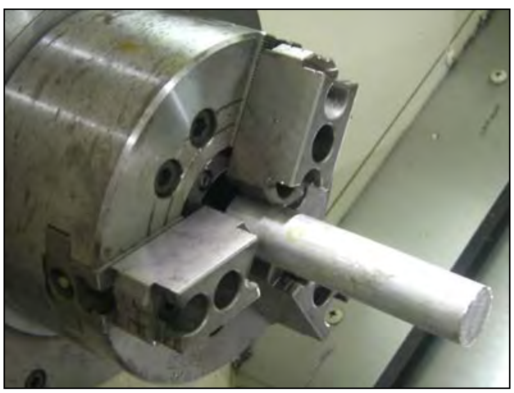
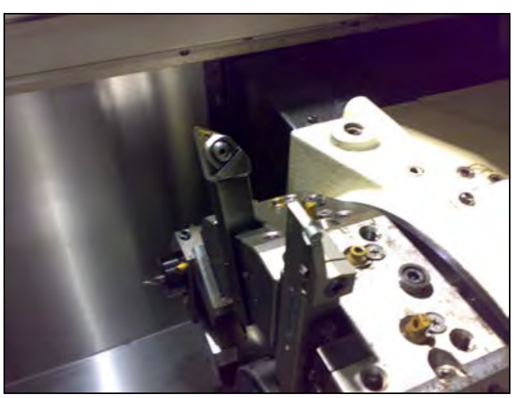
To ensure the experiment can run successfully, the machine and tools needed have been determined. The Okuma Space Turn LB 200-R CNC lathe machine was used to carry out the experiment. This machine was selected due to it is the only available machine that near to the high spindle speed range. Taegu Tec triangle tungsten carbide insert with an angle of 60° was used to do turning process and facing process on the aluminium rod. No coolant was used for both processes because only rough cut has to carry out in the experiments. Rough cut is defined as a cut on the workpiece for the purpose of removing large amounts of material without concern for resulting surface finish. When making a rough cut, the surface finish is of no importance. Also, finish cuts often require certain accuracy that naturally achieves a good surface finish.

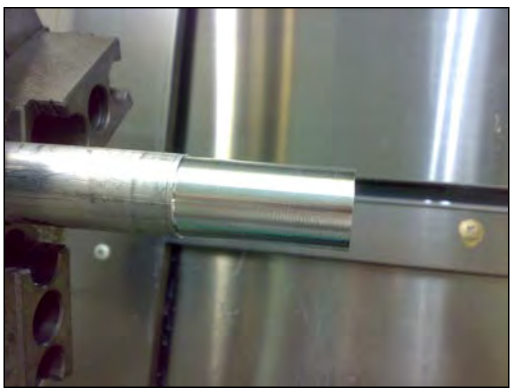
Figure 3.3: Okuma Space Turn LB 200-R CNC lathe machine

Figure 3.4: Taegu Tec triangle tungsten carbide insert

3.4.2 Experimental Method

Table 3.3: Turning Process

	1. The machine was switched on and the aluminium rod was gripped in the chuck.
	2. The tool turret was indexed with reference tool to the working position.

	3. The cutting tool was moved closer at about 500 mm distance from the aluminium rod on both x-axis and z-axis.
	4. Rough cut was done on the aluminium rod to remove a thin layer from it. The distance travelled along the rod was set as 50 mm.
	5. The outer diameter (before) of the aluminium rod is measured by using digital vernier caliper. The reading was recorded in the table.

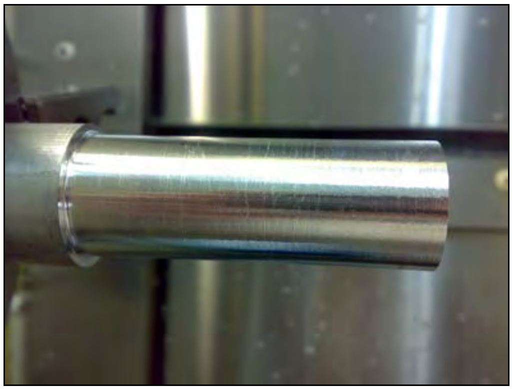
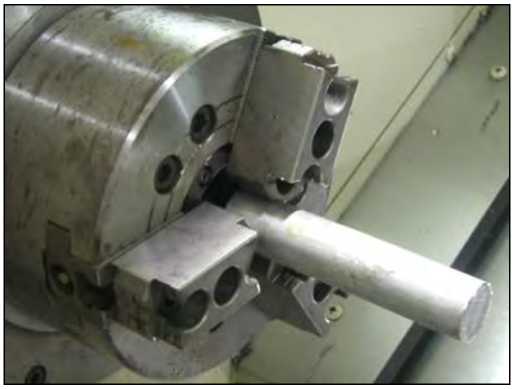
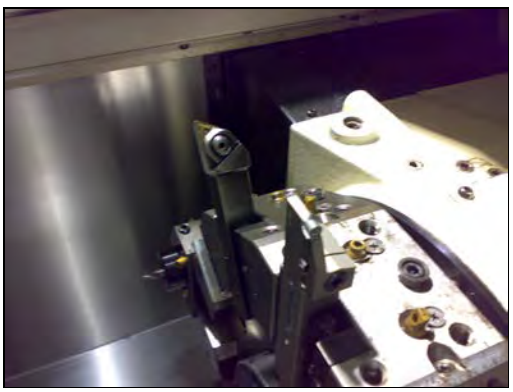
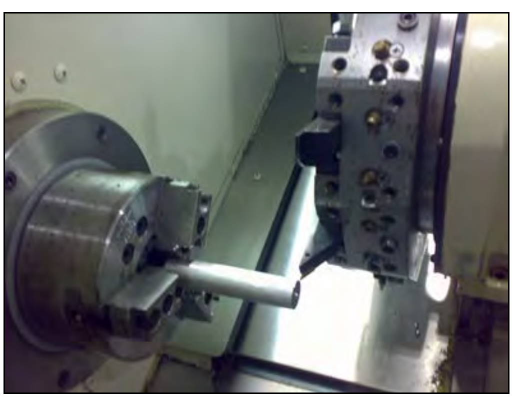
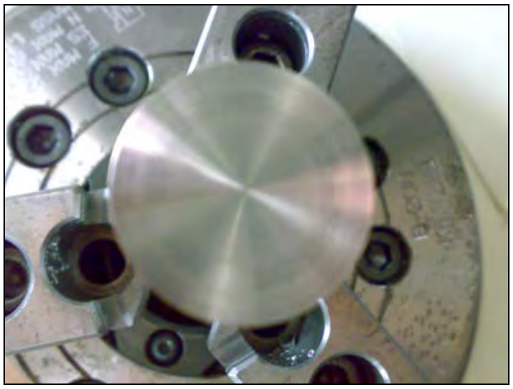
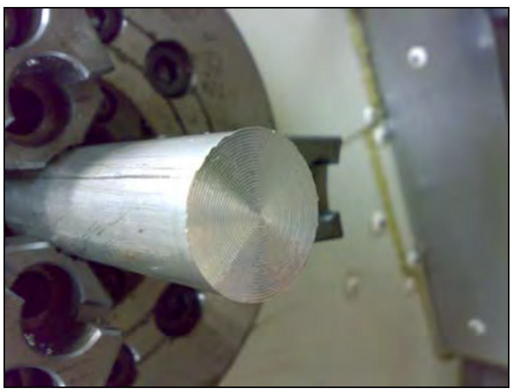
	6. After turning process, the outer diameter the aluminium rod was measured again by using digital vernier caliper. The turning process was repeated on the same rod for one spindle speed.
	7. The surface condition of the aluminium rod and the chip formation after turning were also recorded.
	8. Step 5, 6 and 7 were repeated by key in the different values of spindle speed, feed rate and depth of cut using the control panel as shown.

Table 3.4: Facing Process

	1. The machine was switched on and the aluminium rod was gripped in the chuck.
	2. The tool turret was indexed with reference tool to the working position.
	3. The cutting tool was moved closer at about 500 mm distance from the aluminium rod on both x-axis and z-axis.

	4. Rough cut was done on the face of aluminium rod to remove a thin layer from it.
	5. After facing process, the surface condition of the aluminium rod and the chip formation were recorded in the table.
	6. Step 5 was repeated by key in the different values of spindle speed, feed rate and depth of cut using the control panel as shown.

3.5 Visual Inspection on Aluminium

In this investigation, the surface condition of the aluminium rod was varied by using different level of process parameters. Besides, the chip formation was significantly different with the variation of process parameters. By using visual inspection, the surface condition and chip formation of the aluminium rod were recorded in table. The condition of the cutting tool such as tool wear was also noted down.

CHAPTER 4

RESULTS AND DISCUSSIONS

Through the design of experiments (DOE) method, an experiment matrix was carried out by using the combinations of low, medium and high level of the process parameters. Collections of aggressive turning test data have been accomplished and tabulation of the data has done. The main direction of the analytical work was towards the effect of spindle speed, feed rate and depth of cut on the aluminium. The challenges of aggressive turning such as tool wear, surface condition and chip formation have been investigated for the turning and facing process. Once all the experiment data have been scrutinized, inferences in regard with the objectives of the study has made justified by conclusive results.

Table 4.1: Process parameters and their levels for the experiment

Process Parameters	Low level	Medium level	High level
Spindle speed, n (rpm)	1000	2000	3000
Feed rate, f (mm/rev)	0.15	0.3	0.5
Depth of cut, t (mm)	0.5	1.0	1.5

4.1 Turning Process

Table 4.2: Low level spindle speed for turning process

Spindle Speed, *n* (rpm)	Feed Rate, *f* (mm/rev)	Depth of Cut, *t* (mm)	Diameter Before (mm)	Diameter After (mm)	Difference (mm)	Surface Condition	Chip Formation
1000	0.15	0.5	24.92	24.41	0.51	smooth surface	long, thin, continuous chip
1000	0.15	1.0	24.41	23.40	1.01	smooth surface	long, continuous chip
1000	0.15	1.5	23.40	21.91	1.49	smooth surface	short, continuous chip
1000	0.3	0.5	21.91	21.51	0.40	fine threaded rough surface	long, continuous chip
1000	0.3	1.0	21.51	20.49	1.02	fine threaded rough surface	long, continuous chip
1000	0.3	1.5	20.49	18.99	1.50	fine threaded rough surface	short, continuous chip
1000	0.5	0.5	18.99	18.63	0.36	coarse threaded rough surface	short, thin continuous chip
1000	0.5	1.0	18.63	17.63	1.00	coarse threaded rough surface	short, continuous chip
1000	0.5	1.5	17.63	16.15	1.48	coarse threaded rough surface	short, continuous chip

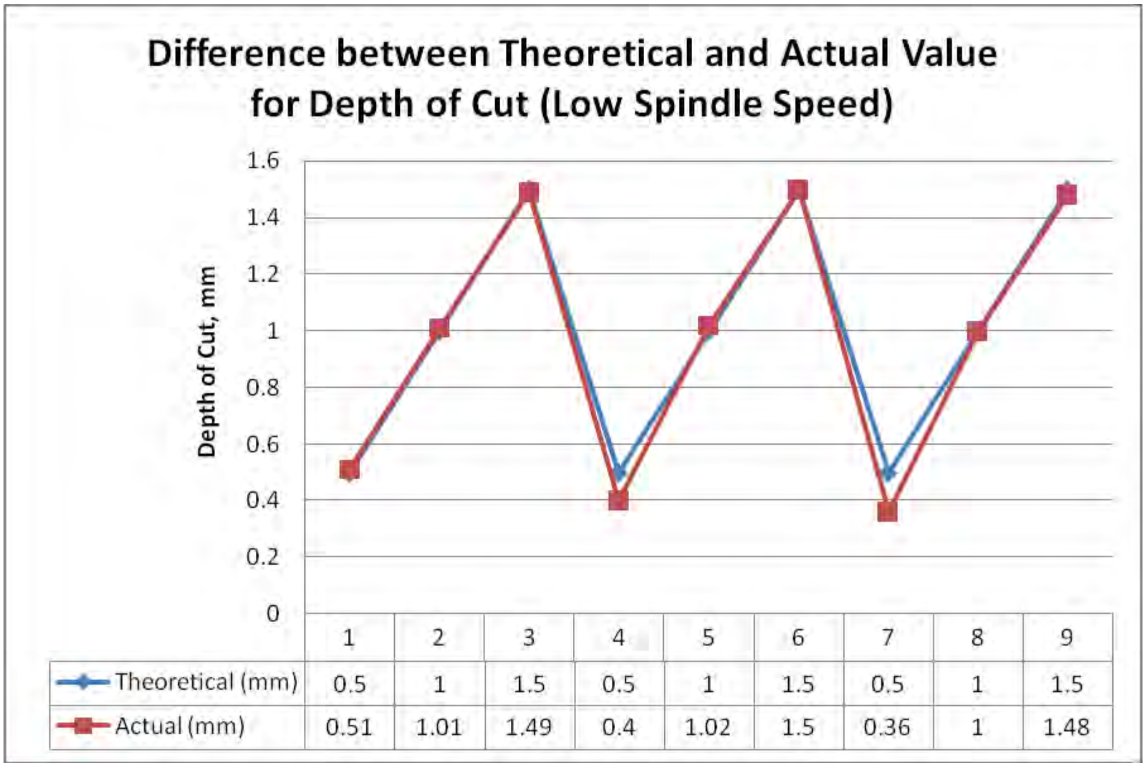


Figure 4.1: Graph of difference between theoretical and actual value for depth of cut (low spindle speed)

For low level spindle speed turning process, when using the low level of depth of cut (0.5 mm), a gradually decrease of the actual depth of cut has been observed as the feed rate was increased. There are only minor difference between theoretical and actual value for medium level and high level of depth of cut. Different level of feed rate showed a different surface condition of the aluminium rod. At low level of feed rate (0.15 mm/rev) a smooth surface of aluminium rod was obtained. The chip formed was a long and thin continuous chip. A fine threaded rough surface and shorter continuous chip were observed at medium level of feed rate (0.3 mm/rev). The surface condition of aluminium rod at high level of feed rate (0.5mm/rev) is even poorer than the surface condition at medium level.

Table 4.3: Medium level spindle speed for turning process

Spindle Speed, *n* (rpm)	Feed Rate, *f* (mm/rev)	Depth of Cut, *t* (mm)	Diameter Before (mm)	Diameter After (mm)	Difference (mm)	Surface Condition	Chip Formation
2000	0.15	0.5	25.13	24.61	0.52	smooth surface	long, thin, continuous chip
2000	0.15	1.0	23.83	22.65	1.18	smooth surface	long, continuous chip
2000	0.15	1.5	21.77	20.16	1.61	smooth surface	short, continuous chip with BUE
2000	0.3	0.5	24.61	24.15	0.46	fine threaded rough surface	long, continuous chip
2000	0.3	1.0	23.83	22.14	1.69	fine threaded rough surface	short, continuous chip
2000	0.3	1.5	20.16	18.69	1.47	fine threaded rough surface	short, continuous chip with BUE
2000	0.5	0.5	24.15	23.83	0.32	coarse threaded rough surface	long, continuous chip
2000	0.5	1.0	22.14	21.77	0.37	coarse threaded rough surface	short, continuous chip
2000	0.5	1.5	18.69	17.21	1.48	coarse threaded rough surface	short, continuous chip with BUE

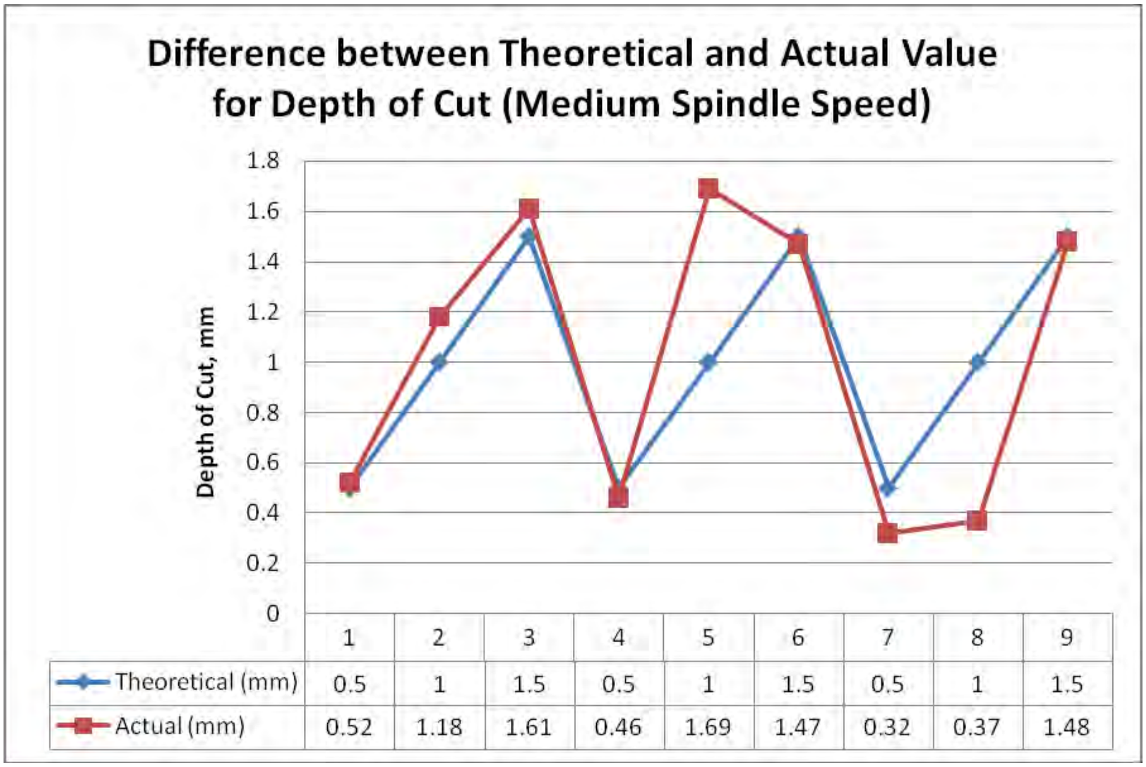


Figure 4.2: Graph of difference between theoretical and actual value for depth of cut (medium spindle speed)

At medium level spindle speed turning process, a fluctuation change of the actual depth of cut was observed. When using the low level of depth of cut (0.5 mm), a gradually decrease of the actual depth of cut has been observed as the feed rate was increased. There were obvious difference between theoretical and actual value for medium level and high level of depth of cut. Different level of feed rate showed a various surface condition of the aluminium rod. A smooth surface of aluminium rod was obtained at low level of feed rate (0.15 mm/rev). The chip formed was a long and thin continuous chip. A fine threaded rough surface and shorter continuous chip were observed at medium level of feed rate (0.3 mm/rev). The surface condition of aluminium rod at high level of feed rate (0.5mm/rev) is even poorer than the surface condition at medium level. At high level of depth of cut (1.5 mm), short continuous chip with built-up edge (BUE) was formed. This type of chip tends to indicate that high friction between aluminium rod and tool causes high temperatures that will occasionally weld the chip to the tool. This tends to cause the cut to be deeper than the tip of the cutting tool and degrades surface finish. The formation of BUE has negative effects on the quality of the aluminium rod; especially a reduction in the dimensional control of the depth of cut which was due to the dynamically changing geometry of the cutting tool.

Table 4.4: High level spindle speed for turning process

Spindle Speed, *n* (rpm)	Feed Rate, *f* (mm/rev)	Depth of Cut, *t* (mm)	Diameter		Difference (mm)	Surface Condition	Chip Formation
			Before (mm)	After (mm)			
3000	0.15	0.5	25.10	24.59	0.51	helical threaded rough surface	long, continuous chip with BUE
3000	0.15	1.0	23.76	22.65	1.11	helical threaded rough surface	long, continuous chip with BUE
3000	0.15	1.5	20.76	19.20	1.56	coarse threaded rough surface	long, continuous chip with BUE
3000	0.3	0.5	24.59	24.18	0.41	helical threaded rough surface	long, continuous chip with BUE
3000	0.3	1.0	22.65	21.65	1.00	coarse threaded rough surface	long, continuous chip with BUE
3000	0.3	1.5	19.20	17.68	1.52	fine threaded rough surface	long, continuous chip with BUE
3000	0.5	0.5	24.18	23.76	0.42	fine threaded rough surface	long, continuous chip with BUE
3000	0.5	1.0	21.65	20.76	0.89	coarse threaded rough surface	long, continuous chip with BUE
3000	0.5	1.5	17.68	N/A	N/A	coarse and uneven surface	long, continuous chip with BUE

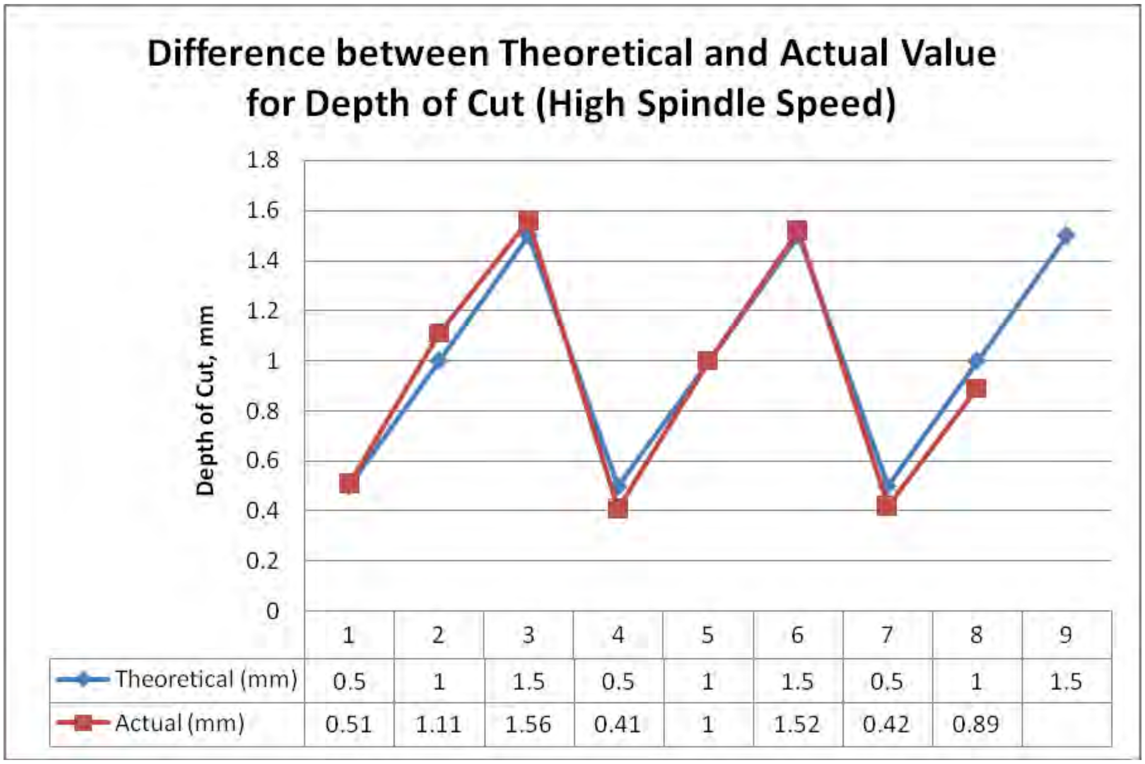


Figure 4.3: Graph of difference between theoretical and actual value for depth of cut (high spindle speed)

At high level spindle speed turning process, a fluctuation change of the actual depth of cut was observed. When using the low level of depth of cut (0.5 mm), a decrease of the actual depth of cut has been observed as the feed rate was increased. There were obvious differences between theoretical and actual value for medium level and high level of depth of cut especially a decrease of 0.11 mm at experiment no.8 (high level feed rate). The surface condition of the aluminium rod was varied at different level of feed rate. No smooth surface has obtained at high level of spindle speed. The chip formed for all high level spindle speed turning process was long and continuous chip with built-up edge (BUE). The formation of BUE has lead to a reduction in the dimensional control of the depth of cut. BUE can be very detrimental to surface finish and integrity, since bits of the BUE eventually break off and stick to the aluminium rod. They effectively change the geometry of the cutting edge and consequently shear plane angle. Experiment no.9 has been stopped during turning process because the chuck was unable to hold the aluminium rod properly. The main cause of this problem was the combination of high level process parameters. The diameter of the aluminium rod cannot be measured due to the coarse and uneven surface. Flank wear on the cutting tool was observed after all 27 experiments for turning process were carried out. The silver residual on the cutting tool indicates that the particles of the aluminium rod weld to the rake face of the tool during turning process. The chips formed are spiral shaped and the chip thickness has increased as the depth of cut was increased for the three levels of turning process.

Figure 4.4: Aluminium rod for experiment no.9

Figure 4.5: Coarse and uneven surface

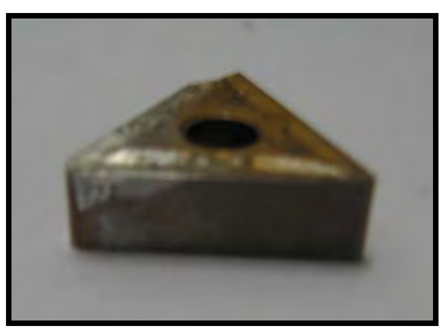


Figure 4.6: Condition of cutting tool after DOE for turning process

4.2 Facing Process

Table 4.5: Low level spindle speed for facing process

Spindle Speed, *n* (rpm)	Feed Rate, *f* (mm/rev)	Depth of Cut, *t* (mm)	Surface Condition	Chip Formation
1000	0.15	0.5	smooth surface	long, thin, continuous chip
1000	0.15	1.0	smooth surface	short, continuous chip
1000	0.15	1.5	smooth surface	long, continuous chip
1000	0.3	0.5	fine threaded rough surface	long, thin, continuous chip
1000	0.3	1.0	fine threaded rough surface	short, continuous chip with BUE
1000	0.3	1.5	fine threaded rough surface	short, continuous chip with BUE
1000	0.5	0.5	coarse threaded rough surface	short, continuous chip with BUE
1000	0.5	1.0	coarse threaded rough surface	short, continuous chip with BUE
1000	0.5	1.5	coarse threaded rough surface	short, continuous chip with BUE

Table 4.6: Medium level spindle speed for facing process

Spindle Speed, *n* (rpm)	Feed Rate, *f* (mm/rev)	Depth of Cut, *t* (mm)	Surface Condition	Chip Formation
2000	0.15	0.5	scratched marks on surface	long, thin, continuous chip
2000	0.15	1.0	scratched marks on surface	short, continuous chip
2000	0.15	1.5	scratched marks on surface	short, continuous chip
2000	0.3	0.5	fine threaded rough surface	long, continuous chip with BUE
2000	0.3	1.0	fine threaded rough surface	short, continuous chip with BUE
2000	0.3	1.5	fine threaded rough surface	short, continuous chip with BUE
2000	0.5	0.5	coarse threaded rough surface	short, continuous chip with BUE
2000	0.5	1.0	coarse threaded rough surface	short, continuous chip with BUE
2000	0.5	1.5	coarse threaded rough surface	short, continuous chip with BUE

Table 4.7: High level spindle speed for facing process

Spindle Speed, *n* (rpm)	Feed Rate, *f* (mm/rev)	Depth of Cut, *t* (mm)	Surface Condition	Chip Formation
3000	0.15	0.5	smooth surface	long, thin, continuous chip
3000	0.15	1.0	fine threaded rough surface	long, continuous chip
3000	0.15	1.5	fine threaded rough surface	long, continuous chip
3000	0.3	0.5	fine threaded rough surface	short, continuous chip with BUE
3000	0.3	1.0	fine threaded rough surface	short, continuous chip with BUE
3000	0.3	1.5	fine threaded rough surface	short, continuous chip with BUE
3000	0.5	0.5	coarse threaded rough surface	short, continuous chip with BUE
3000	0.5	1.0	coarse threaded rough surface	short, continuous chip with BUE
3000	0.5	1.5	coarse threaded rough surface	short, continuous chip with BUE

It can be seen in the figures (refer Appendix D) that there were scratched marks on the surface of aluminium rod at medium level spindle speed and low level feed rate of 0.15 mm/rev. This could be due to the abrasive action of microhard carbide particles present in the material. At low level of feed rate, a thin and long continuous chip tends to form and a smooth surface was obtained. The increase of feed rate has caused the formation of shorter chip. The chips formed are spiral shaped. One common phenomenon for the three levels of facing process was the chip thickness has increased as the depth of cut was increased. The deformation of chip is generally found to be inhomogeneous. Experimental values show that the surface roughness values increases with feed rate. The formation of built up edge has occurred with the increasing of feed rate and depth of cut which has affect the surface quality of the aluminium rod. The absence of cutting fluid was also one of reason. Besides that, the silver residual on the cutting tool indicates that the particles of the aluminium rod weld to the rake face of the tool during facing process. No crack or breakage of the cutting tool was observed.

For both turning process and facing process which were conducted by using DOE metod, the optimum parameters were selected based on the surface condition, cutting tool condition and the formation of the chips. It can be summarized as below:

Table 4.8 Optimum parameters for turning process and facing process

Turning Process	Facing Process
Spindle Speed, *n*: 2000 rpm	Spindle Speed, *n*: 3000 rpm
Feed Rate, *f*: 0.15 mm/rev	Feed Rate, *f*: 0.15 mm/rev
Depth of Cut, *t*: 0.5 mm	Depth of Cut, *t*: 0.5 mm

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

By increasing the spindle speed, machining time per workpiece can be reduced. The workpiece is machined more rapidly and spends less time in the machine tool. High speed is a relative term varying from one work material to another making the definition of such a concept rather difficult. More recently, there has been a flurry of trade journal articles addressing the issue of high-speed machining in general and drilling in particular. Thus, the high speed machining range is not suitable to use in terms of aggressive turning. Feed rate is the variable that has the most important effect on surface roughness. If aggressive turned the aluminium, feed rate cannot increase further due to a poor surface finish will be obtained. In order to improve production rate and obtain a good surface finish, the spindle speed should be increased by lowering feed rate and depth of cut. Tool wear is very much dependent on cutting condition. The results obtained from the design of experiment have shown that the flank wear was affected significantly by the spindle speeds and feed rates. As a conclusion, the study of aggressive turning on aluminium for automotive applications is an effort to improve production rate help the industry to save time and cost by controlling the process parameters using DOE method.

5.2 Recommendations

The following are suggestions in the event of similar future studies:

1. Search for the suitable CNC lathe machine which can run high spindle speed from other universities or workshop.

2. Besides the effect of surface roughness, tool wear, and chip formation on aluminium, the study of the effect of heat to the aluminium should be carried out.

3. Use the aluminium that suitable for automotive applications such as aluminium 6061 in the studies.

4. In order to more accurate results, the design of experiments can be repeated several times using different combinations of process parameters. The range for feed rate and depth of cut can be lower to obtain a good surface finish

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Appendix A: PSM Planning Schedule

PSM 1

No	Task	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Planning	■													
2	Discussion with supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■
3	Literature research	■	■	■	■	■	■	■	■	■	■	■	■	■	
4	Introduction	■	■												
5	Literature Review			■	■	■	■								
6	Methodology							■	■	■	■				
7	Expected Results and Discussion											■	■		
8	Conclusion													■	
9	Submit Report														■

PSM 2

No	Task	Week																		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1	**Planning**																			
2	**Discussion with supervisor and technician**																			
3	**Project Implementation**																			
	Design table for DOE																			
	Execution of experiment																			
4	**Compiling and analysis of data**																			
	Analyze data																			
	Further literature research and reconfirm observations																			
	Compile Chapter 3 and 4 (Prepare draft PSM report)																			
5	**PSM 2 report and presentation**																			
	Final editing of PSM report																			
	Submit PSM report																			
	PSM presentation																			

Appendix B: Okuma Space Turn LB 200-R

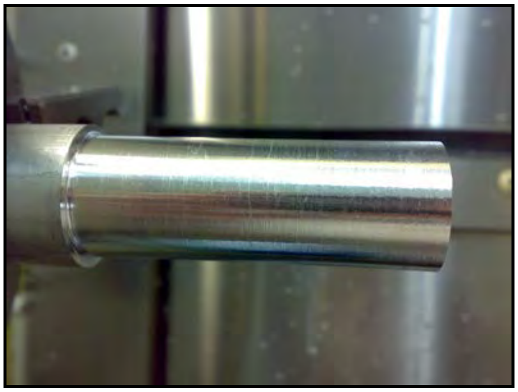
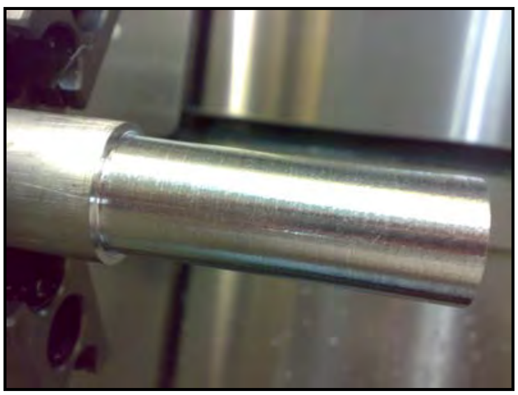
OKUMA - SPACE TURN LB200	
Cena	Dohoda - kontaktujte mne.
Max turning dia mm 230 Max work length mm 300 Spindle speed min-1(rpm) 50~6000 Turret V12 Motor (VAC) mm 230 Max work length mm 300 Spindle Arial, Helvetica, sans-serif>kW 7.5/5.5 Floor space mm 1985 × 1720	

The figure depicts the specification of Okuma Space Turn LB 200-R

Appendix D: Figures of the Turning Process and Facing Process

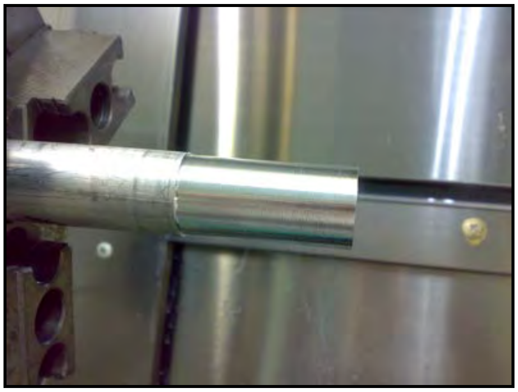
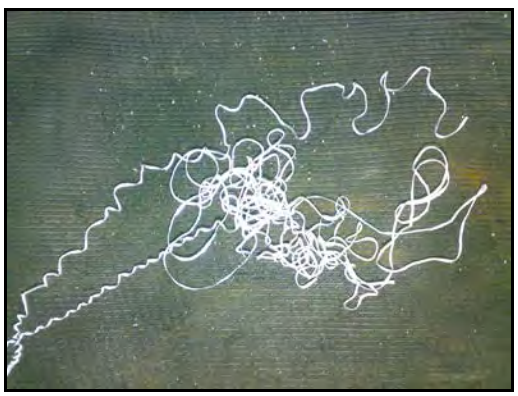
Turning Process (Low level spindle speed)

Surface Condition

Low Feed Rate 	Spindle Speed = 1000 rpm Feed Rate = 0.15 mm/rev Depth of Cut = 1.5 mm
Medium Feed Rate 	Spindle Speed = 1000 rpm Feed Rate = 0.3 mm/rev Depth of Cut = 0.5 mm
High Feed Rate 	Spindle Speed = 1000 rpm Feed Rate = 0.5 mm/rev Depth of Cut = 1.0 mm

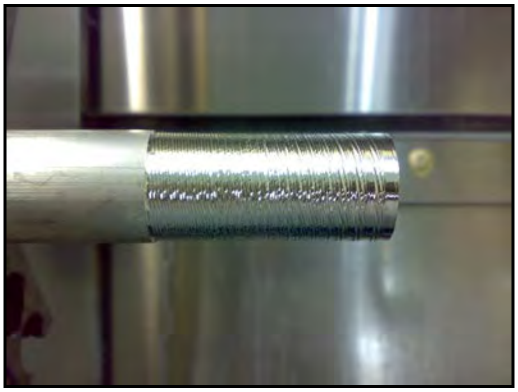
Turning Process (Medium level spindle speed)

Surface Condition and Chip Formation

	Spindle Speed = 2000 rpm Feed Rate = 0.3 mm/rev Depth of Cut = 0.5 mm
Low Feed Rate 	Medium Feed Rate 
High Feed Rate 	

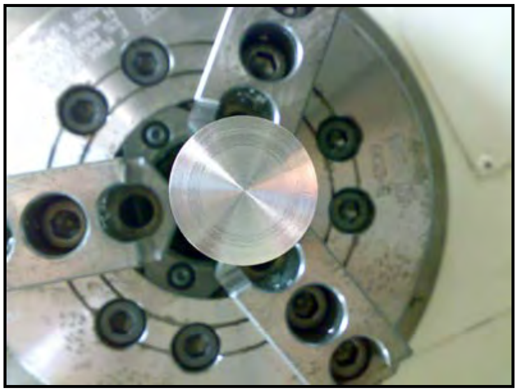
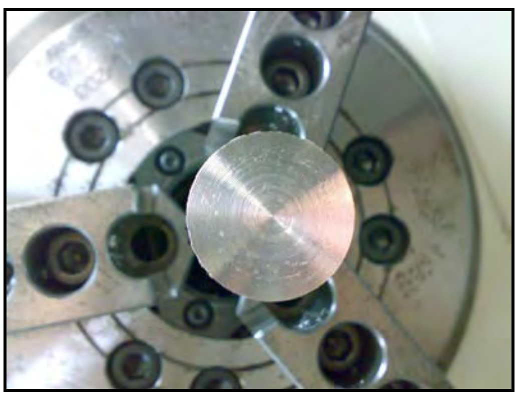
Turning Process (High level spindle speed)

Surface Condition and Chip Formation

	Spindle Speed = 3000 rpm Feed Rate = 0.15 mm/rev Depth of Cut = 0.5 mm
Low Feed Rate 	Medium Feed Rate 
High Feed Rate 	

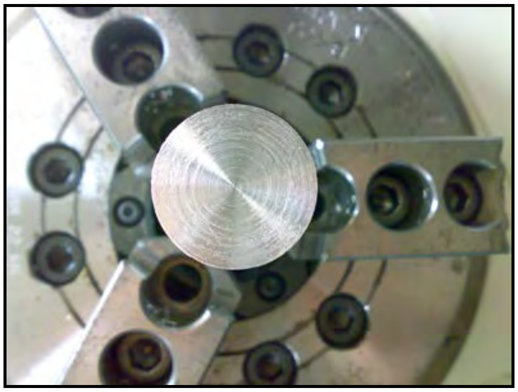
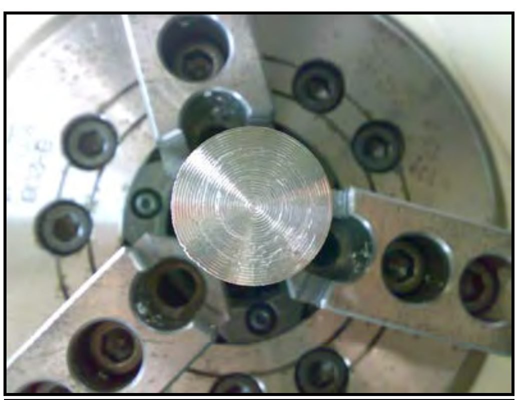
Facing Process (Low level spindle speed)

Surface Condition and Chip Formation

Low Feed Rate 	
Medium Feed Rate 	
High Feed Rate 	

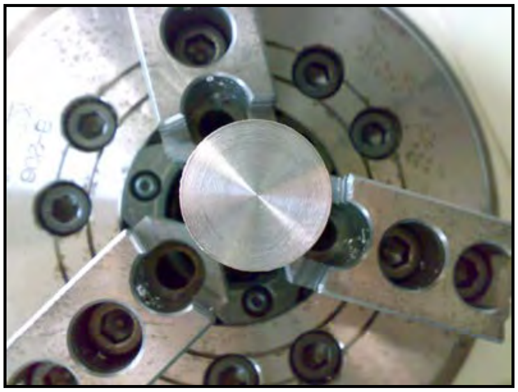
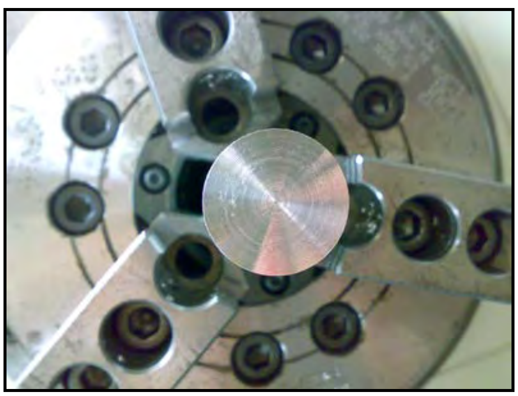
Facing Process (Medium level spindle speed)

Surface Condition and Chip Formation

Low Feed Rate 	
Medium Feed Rate 	
High Feed Rate 	

Facing Process (High level spindle speed)

Surface Condition and Chip Formation

Low Feed Rate 	
Medium Feed Rate 	
High Feed Rate