COMPARISON STUDIES OF MACHINABILITY FOR ALUMINUM, MILD STEEL AND HEAT TREATED MILD STEEL

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A dissertation submitted in partial fulfillment of
the requirement for the award of
Bachelor of Mechanical Engineering

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APRIL 2008

ABSTRACT

In recent years, industry spend almost quarter amount of the actual annual spend only for performing the metal removal operation. In order to cut this amount, it is necessary to understand the machining process that shall be done and the machinability of the material. While machining is the process designed to change the size, shape, and surface of a material through removal of materials, machinability came as important as the ease with which it can be machined. However, machinability is not a property of a material but an attribute. With this attribute, there are four major factors which are surface roughness, chip formation, tool life and cutting force. Material made of aluminum and mild steel is widely use since they are the cheapest material compare to the other steel that not require very high strength. Therefore, to manufacture components economically, engineers are challenged to find ways to improve machinability without harming performance. Machinability can be difficult to predict because machining is such a complex process. In short, a good material with good machinability is the one that require low power consumption, low tool life and have high surface finish rate without surface damage.

ABSTRAK

Kebelakangan ini, insdustri besar menghabiskan hampir ¼ daripada bajet tahunan yang sebenar hanya untuk membuat operasi memisahkan metal. Bagi mengelakkan kekurangan bajet, adalah penting untuk kita mengetahui jenis proses *machining* yang akan dijalankan dan *machinability* sesuatu material. *Machining* boleh dikatakan sebagai proses untuk merubah saiz, bentuk dan permukaan menerusi proses pemisahan metal, *machinability* pula memainkan peranan penting sebagai kebolehan sesuatu material untuk dimesinkan. Bagaimanapun, machinability bukanlah satu sifat bahan, tetapi sebagai satu keutamaan . Dengan keutamaan ini, terdapat empat factor yang mempengaruhinya iaitu kelicinan permukaan, bentuk *chip*, jangka hayat alat dan kuasa yang diperlukan. Material yang digunakan bagi projek ini pula adalah aluminium dan mild steel kerana material ini merupakan bahan mentah yang paling murah berbanding dengan material lain. Untuk ini, jurutera masa kini menempuh cabaran baru untuk mencari jalan bagi meningkatkan *machinability* sesuatu bahan tanpa membabitkan kebolahan material tersebut. *Machinability* tidak boleh dijamgka kerana melalui proses-proses pemesinan yang komplex. Dengan kata lain, material yang mempunyai *machinability rate* yang tinggi adalah material yang hanya memerlukan sedikit kuasa yang digunakan, jangka hayat alat yang panjang dan mempunayi permukaan yang licin selepas menjalani proses pemesinan.

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v	cutting speed
T	tool life
n	constant value for the type of tool
C	value for the cutting speed when T=1 minute
d	depth of cut
P	power
f	cutting force

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CHAPTER 1

INTRODUCTION

1.0 Description

The history of machine tools began during the Stone Age (over 50000 years ago), when the only tools that were used were made of wood, animal bones, or stone. These tools which were hand tools made gave a big contribution to the development of world nowadays especially to the industries field.

With the industrial revolution in the mid18th century, every machine tool were developed and improved. Since the Machine Age started, all the machines were created based on new source of technologies such as water power till electrical energy today (Figure 1). Through constant improvement, modern machine tools have become more accurate and efficient. Improved production and accuracy have been made possible through the application of hydraulics, pneumatics, fluidics and electronics devices such as computer numerical control (CNC) to basic machine tools (Kalpakjian, 2000)

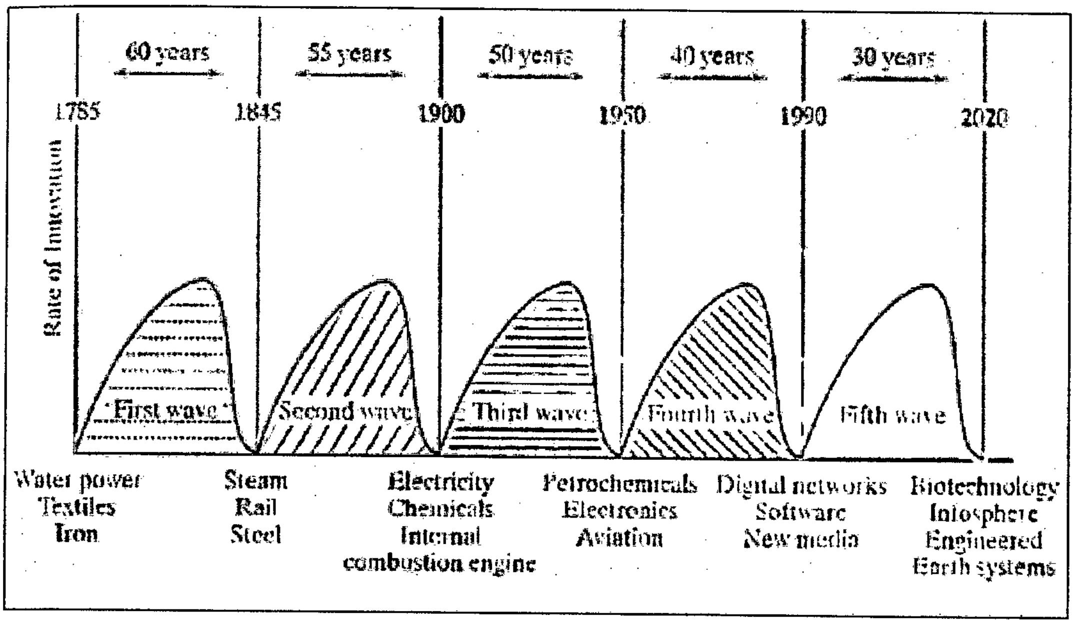

Figure 1.1 Wave of technology

(*Source, Paul. Sheng, 2000*)

However, in industrials today, machining become the most important of the manufacturing processes in term of annual money spend. Machining can be defined as the process of removing material from a workpiece in the form of chips and will discuss more in the next chapter. Machining is much more expensive for high volumes and is necessary where high tolerances on dimensions and finishes are required. Simply, we can assume the economic consideration needed on machining as below;

i. Numbers required;
   - Large numbers reduces unit product costs
     - Permits the use of complex machinery
     - Advanced manufacturing methods

ii. Capital investment
   - Equipment costs
   - Operating and labor costs
   - Flexibility

iii. Conversion costs
   - Process steps
   - Production rates

- Inventory and space requirements
- Scrap generation and handling costs

The machinability of a material can be defined as the ease with which it can be machined. This depends on the physical properties of the material, as well as on the cutting conditions. Machinability on different materials also is a critical property that controlling the product economy in the manufacture of engineering components. A material with good machinability is the one requiring low power consumption, with low tool wear and producing a good surface finish with no surface damage.

In short, this study is to investigate the influence of different cutting parameters, e.g. cutting speed, feed and depth of cut on the cutting force and the surface finish criteria using aluminum, and both of mild steel and heat treated mild steel.

1.1 Objectives and Aim of the Project

- To identify the suitable material with good machinability
- To verify machinability of different materials and their effect on machining process

1.2 Scope of the Project

This study is carried out to investigate the influence of different materials effect on its machinability during the machining process by setting all the parameter to be the same.

1.3 Problem Statement

As seen, design and manufacturing must be intimately interrelated as they should never be viewed as separate disciplines or activities. Each part or component of a product must be designed so that it not only meets design requirement and specification, but also can be manufactured economically and efficiently. This approach improves productivity and allows a manufacturer to remain competitive.

However, in this project, the design is not to be seen as a manufacture product but to estimate the best material with most machinability rate.

1.4 Justification

The study is carried out to find the most economical material with good machinability by investigating the influence machinability.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

In this chapter, all the main point of the purpose of this project will be defined totally. The first point is the mechanical properties of the materials selected which are aluminum, mild steel and the heat treated mild steel. These materials are selected according to their unique properties and so on. Here also will be discussed on the summary of mechanical properties.

The second one is about machining and machinability of materials. At this point, the machining process of cutting and how good a material on machinability criteria will be discussed. And the last one is fundamental of cutting where all the parameter of machining will be discussed.

2.1 Mechanical Properties

The mechanical properties of most interest and the ones that will always be considered include yield strength, ultimate tensile strength, modulus of elasticity, ductility, hardness, fatigue, creep and fracture. The strength, modulus and ductility are of prime importance and are most often determined in a uniaxial tension test. Some materials are equally strong in compression, tension, and shear. However, many materials show marked differences; for example, cured concrete has a maximum strength of 2,000 psi in compression, but only 400 psi in tension. Carbon steel as example has a maximum strength of 56,000 psi in tension and compression but a maximum shear strength of only 42,000 psi, therefore, when dealing with maximum strength, it is always should to state the type of loading.

A material that is stressed repeatedly usually fails at a point considerably below its maximum strength in tension, compression, or shear. For example, a thin steel rod can be broken by hand by bending it back and forth several times in the same place; however, if the same force is applied in a steady motion (not bent back and forth), the rod cannot be broken. The tendency of a material to fail after repeated bending at the same point is known as fatigue. And yet, the following are the simplified of the main mechanical properties that usually always being discussed on materials.

2.1.1 Strength

Strength is the property that enables a metal to resist deformation under load. The ultimate strength is the maximum strain a material can withstand. Tensile strength is a measurement of the resistance to being pulled apart when placed in a tension load.

Fatigue strength is the ability of material to resist various kinds of rapidly changing stresses and is expressed by the magnitude of alternating stress for a specified number of cycles.

Impact strength is the ability of a metal to resist suddenly applied loads and is measured in foot-pounds of force.

2.1.2 Hardness

Hardness is the property of a material to resist permanent indentation. Because there are several methods of measuring hardness, the hardness of a material is always specified in terms of the particular test that was used to measure this property. Rockwell, Vickers, or Brinell are some of the methods of testing. Of these tests, Rockwell is the one most frequently used. The basic principle used in the Rockwell testis that a hard material can penetrate a softer one. We then measure the amount of penetration and compare it to a scale. For ferrous metals, which are usually harder than nonferrous metals, a diamond tip is used and the hardness is indicated by a Rockwell "C" number. On nonferrous metals, that are softer, a metal ball is used and the hardness is indicated by a Rockwell "B" number. To get an idea of the property of hardness, compare lead and steel. Lead can be scratched with a pointed wooden stick but steel cannot because it is harder than lead.

A full explanation of the various methods used to determine the hardness of a material is available in commercial books or books located in your base library.

2.1.3 Toughness

Toughness is the property that enables a material to withstand shock and to be deformed without rupturing. Toughness may be considered as a combination of strength and plasticity.

2.1.4 Elasticity

When a material has a load applied to it, the load causes the material to deform. Elasticity is the ability of a material to return to its original shape after the load is removed. Theoretically, the elastic limit of a material is the limit to which a material can be loaded and still recover its original shape after the load is removed.

2.1.5 Plasticity

Plasticity is the ability of a material to deform permanently without breaking or rupturing. This property is the opposite of strength. By careful alloying of metals, the combination of plasticity and strength is used to manufacture large structural members. For example, should a member of a bridge structure become overloaded, plasticity allows the overloaded member to flow allowing the distribution of the load to other parts of the bridge structure.

2.1.6 Brittleness

Brittleness is the opposite of the property of plasticity. A brittle metal is one that breaks or shatters before it deforms. White cast iron and glass are good examples of brittle material. Generally, brittle metals are high in compressive strength but low in tensile strength.

2.1.7 Ductility and Malleability

Ductility is the property that enables a material to stretch, bend, or twist without cracking or breaking. This property makes it possible for a material to be drawn out into a thin wire. In comparison, malleability is the property that enables a material to deform by compressive forces without developing defects. A malleable material is one that can be stamped, hammered, forged, pressed, or rolled into thin sheets.

2.2 Low Carbon Steel (Mild Steel)

The handbook of the US steel industry, the *Steel Product Manual*, published by the Iron and Steel Society, universally describe carbon steels as steels with up to 2% carbon and only residual amount of other element except those added for deoxidation (for example, aluminum), with silicon limited to 0.6%, copper to 0.6% and manganese to 1.65%. In other words, steels are iron-based metals to which other chemical elements have been added. The addition of these elements can create new constituents in the metal, affecting its mechanical properties (hardness, tensile and yield strength, ductility) and machinability (Krar, 2005). Steels are considered to be carbon steel when no minimum content is specified for chemical elements including aluminum, chromium, cobalt, columbium, molybdenum, nickel, titanium, tungsten or vanadium for alloying effect; when the specified minimum for copper is 0.40 or less; and when the limits for the following elements are not exceeded: manganese-1.65%, silicon-0.60% and copper-0.60 % while yet the American Iron and Steel Institute (AISI) defines a carbon steel as having no more than 2 % carbon and no other appreciable alloying element.

Though, both of the materials that are selected for this study is applied to another class of steel which is low carbon steel (mild steel). Serope Kalpakjian in his book *Manufacturing Engineering and Technology* stated that carbon steel are generally classified by their proportion (by weight) of carbon content and the class of low carbon steel has less than 0.30% carbon. It is generally used for common industrial products such as bolts, nuts, sheet, plate and tubes and for machine component that do not require high strength. This statement is agreed by Dominic. C. Richards from Birmingham's Finest - Minehead, Somerset, England on 22nd of January 2007 in his answer on the internet forum *'What is Mild Steel'* claimed that the mild steel is iron alloy with 0.3% carbon and the main properties are malleable and ductile-therefore bend fairly easily. According to Dominic also, mild steel is the most common form of steel as its price is relatively low while it provides material properties that are acceptable for many applications. It is also often used where large amount of steel need to be formed, for example as structural steel.

2.3 Aluminum

In *Engineering Materials Technology* book by James A. Jacobs and Thomas F. Kilduff, aluminum alloys have found wide acceptance in engineering design primarily because they are relatively lightweight, have high strength to weight ratio, have superior corrosion resistance, and they are comparatively inexpensive. According to them, for some applications aluminum is favored as their high thermal and electrical conductivity, ease of fabrication, and ready availability. It is nonmagnetic and non-sparking. Its density is 2.6989 g/cm^3, melting point 669.7°C and boiling point 1800°C. Its electrical resistivity is 2.824 µΩ-cm at 20°C, with temperature coefficient 0.0039°C^{-1}, the same as copper's. Its thermal conductivity is 2.37 W/cm-K at 300K, and the linear coefficient of expansion is 23.86 x 10^{-6}°C^{-1}. The specific heat is 0.2259 cal/g-K, and the heat of fusion is 93 cal/g.

Generally, the strength of aluminum alloys decrease and toughness increase with in increase in temperature, and with time at temperature above room temperature. The effect is usually greatest over the temperature range between 100 to

204°C. Further time at temperature beyond that required to achieve peak hardness results in the aforementioned decrease in strength and increase toughness.

Corrosion resistance of aluminum is attributes to its self-healing nature – a thin invisible skin of aluminum oxide forms when the metal is exposed to the atmosphere. More pure the element means the more continuous of aluminum to perform a protective oxide film, while high strength alloyed forms will sometimes become pitted as a result of localized galvanic corrosion at sites of alloying-constituent concentration (Wilson, 1944). As a Conductor of electricity, aluminum is more favorable compare to the copper as an advantage on the weight and space requirement. As a heat conductor, aluminum ranks high among the metals. It is especially useful in heat exchangers and other applications that requiring rapid heat dissipation.

And based on William D. Callister Jr. in his book entitle *Materials Science and Technology an Introduction* claimed that aluminum is eases fabricated material. It can be cast by any method, rolled to any reasonable thickness, stamped, hammered, forged or extruded. It is readily turned, milled, bored or machined. It also can be joining by several welding process. Moreover, aluminum can be also coated with a wide variety of surface finish for decorative and protective purpose.

2.3.1 1100 Aluminum

With few exceptions, aluminum alloys are designed either for casting or for use in wrought product, but not for both as some general purpose alloys are available but, on the whole, compositions are formulated to satisfy specific requirement. 1100 aluminum is in 1xxx series – pure aluminum. This series is made up of commercially pure aluminum, ranging from the baseline 1100 (99.00% minimum Al) to relatively purer 1050/1350 (99.50% min.) and 1175 (99.75% min.).

The 1xxx series are strain hardenable, but would not be used where the strength is prime consideration. Instead, the emphasis would be on those applications where extremely high corrosive resistance, high formability or good electrical conductivity is required. Examples are foil and strip for packaging, chemical equipment and elaborate sheet metal work.

Table 2.1 Chemical Composition of Wrought Aluminum and Aluminum Alloys

(Source, Aluminum Association, Inc.)

Series of 1xxx Alloy	**1100**
Si	0.95 Si + Fe
Fe	
Cu	0.05-0.20
Mn	0.05
Mg	-
Cr	-
Zn	0.10
Ti	-
V	-
other (unspecified)	Each:0.03 Total: 0.15
Al	**99.0 min**

Table 2.2 Mechanical Properties of Wrought Aluminum Alloys

(Source, Aluminum Association, Inc.)

Series of 1xxx Alloy	**1100 (annealed)**
Ultimate Tensile Strength	90 MPa
Tensile Yield Strength	34 MPa
Ultimate Shearing Strength	62 MPa
Fatigue Endurance Limit	34 MPa
Elongation %	For 0.0625" thick: 35
	For 0.50 diameter: 45
Brinell Hardness	BHN: 23

Table 2.3 Physical Properties of Wrought Aluminum Alloys

(Source, Aluminum Association, Inc.)

Series of 1xxx Alloy	1100 (annealed)
Density (lb/cu in.)	0.098
Thermal conductivity (Eng.[2])	1540
Coefficient Thermal Expansion (μm °C)	23.6
Electrical (conductivity[3])	59
Melting Point (°C)	Solidus: 643
	Liquidus[4]:655

2.4 Machining and Machinability

2.4.1 Machining

In terms of annual dollars spent, machining is the most important of the manufacturing processes. Machining can be defined as the process of removing material from a workpiece in the form of chips. The term metal cutting is used when the material is metallic. Most machining has very low set-up cost compared to forming, molding, and casting processes. However, machining is much more expensive for high volumes. Machining is necessary where high tolerances on dimensions and finishes are required.

Machining is the broad term used to describe removal of material from a workpiece; it covers several processes, which can usually divide into the following categories

i. Cutting, generally involving single-point or multipoint cutting tools, each with a clearly defined geometry
ii. Abrasive processes, such as grinding.

iii. Advance machining processes that utilize electrical, chemical, thermal and hydrodynamic method, as well as lasers.

Paul Hudson in his article on the internet *Manufacturing Process and Techniques* said that all machining processes remove material to form shapes. As metals are still the most widely used materials in manufacturing, machining processes are usually used for metals. However, machining can also be used to shape plastics and other materials which are becoming more widespread. Basically all the different forms of machining involve removing material from a component using a rotating cutter. The differences between the various types arise from the relative motion between cutting tool and workpiece and the type of cutting tool used.

He also said that nowadays, typically machining will be done using a machine tool. This tool holds the workpiece and the rotating cutting tool and allows relative movement between the two. Usually machine tools are dedicated to one type of machining operation, although some more flexible tools allow more than one type of machining to be performed. The machine tool can either be under manual or automatic (Computer Numeric Control - CNC) control. Automatic control is more expensive because of the need to invest in the necessary control mechanisms however it becomes more desirable as the number of components produced increases and labor costs can be reduced.

The speed at which a machine tool can process individual components is a function of the cutting speed of the tool and the downtime involved in changing the workpiece and maintaining the tool (this will usually involve changing the cutting edges of the tool). Some very flexible tools allow automatic changing of components and cutting tools, however they greatly add to initial purchase price of the machine tool.

The cutting speed of the tool is usually dictated by the type of material being machined, in general the harder the material, the slower the machining time. Machining speed can be increased by increasing the rotational speed of the cutter; however this will be at the expense of the tool life. Hence for machining processes there is an optimum cutting speed that balances tooling costs with cutting speed.

In order to dissipate the heat generated between the workpiece and the cutting tool, cutting fluids are sprayed onto the tool. The cutting fluid also acts to remove cut material away from the cutting region and lubricates the tool - workpiece interface but may require that the component is cleaned afterwards.

2.4.2 Machinability

Machinability is not a property of the material but is an attribute. With this attribute, there are 4 factors to consider which are;

i. Surface finish and integrity of machined part
ii. Tool life obtained
iii. Force and power requirement
iv. Chip control

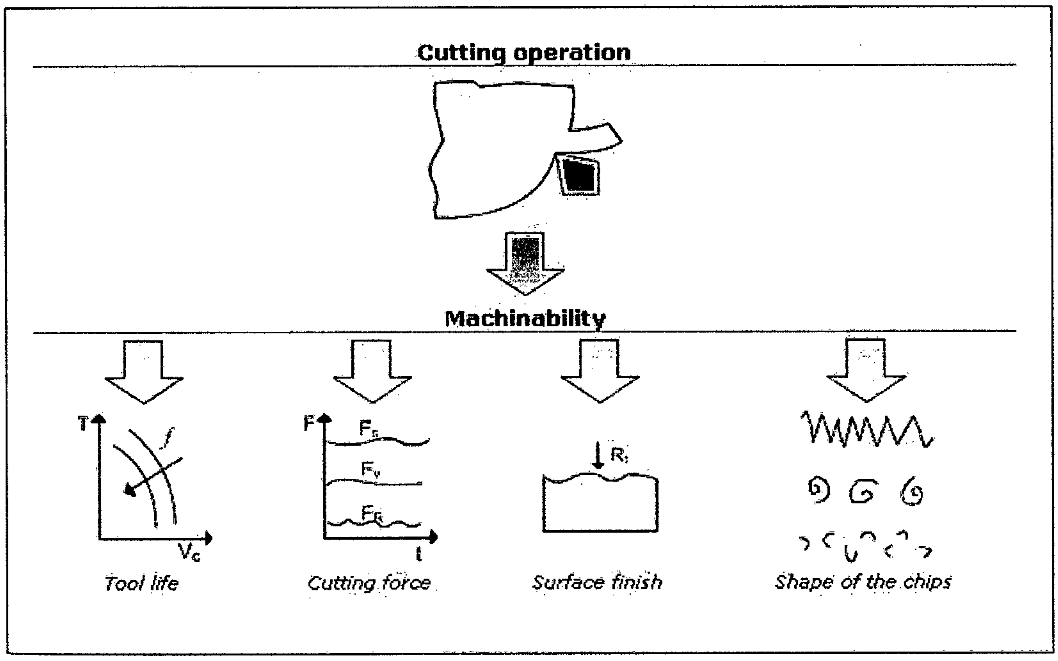

Figure 2.1 Factor that consider machinability

(Source, http://aluminium.matter.org.uk/default.asp)

Serope argued that good machinability indicates good surface finish and integrity, long tool life and low force requirement. As for chip control, long and thin