INVESTIGATION OF MECHANICAL PROPERTIES AND MICROSTRUCTURE WHEN PROCESSING ALUMINA-BASED CUTTING TOOL UNDER DIFFERENT PRESSURE USING COLD ISOSTATIC PRESSURE (CIP)

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons)

by

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Tajuk: **INVESTIGATION OF MECHANICAL PROPERTIES AND MICROSTRUCTURE WHEN PROCESSING ALUMINA-BASED CUTTING TOOL UNDER DIFFERENT PRESSURE USING COLD ISOSTATIC PRESSURE (CIP)**

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons.).

The members of the supervisory committee are as follows:

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ABSTRAK

Pemotong perkakas seramik merupakan antara perkakas yang kerap digunakan dalam operasi pemesinan terutama pada kondisi kering. Kelebihan seramik seperti kekerasan panas tinggi dan refraktori tinggi yang membolehkan ia diaplikasikan dalam pemesinan besi keras. Proses penghasilan mata alat dengan kaedah teknologi serbuk adalah satu kaedah yang digunakan secara meluas pada masa kini terutama untuk mata alat yang diperbuat daripada bahan seramik. Kajian ini tertumpu kepada peningkatan kepadatan seramik berasaskan alumina untuk meningkatkan pretasi sifat dengan empat tekanan yang berbeza iaitu tiada tekanan, 250 MPa, 300 MPa, dan 350 MPa mengunakan mesin Cold Isostatic Press (CIP). Oleh itu, kesan profil CIP ini dikaji bagi menghasilkan produk akhir yang mempunyai ciri-ciri seperti struktur mikro yang baik, kekuatan yang tinggi dan ketumpatan yang tinggi. Serbuk alumina semburan kering digunakan sebagai bahan utama untuk penghasilan perkakas pemotong ini. Ia melibatkan tiga kaedah utama dimana yang pertama bahan mentah yang bersaiz mikrometer dengan mengunakan ball milling selama 12 jam. Kemudian proses yang kedua, serbuk akan dimampatkan kedalam acuan dengan mengunakan penekan hidraulik pada tekanan 5 tan sebelum dimampatkan lagi melalui tekanan isostatik sejuk pada tiada tekanan, 37000 psi, 44000 psi, dan 51000 psi. Seterusnya, yang ketiga serbuk yang telah dibentuk akan dikeringkan dan di bakar atau ‘sintered’ pada suhu 1400 °C selama 9 jam. Produk akhir yang dihasilkan dengan kaedah ini akan dinilai sifat mekanik seramik seperti pengukuran kepadatan relative, ujian kekerasan Vicker, ujian pengecutan dan kajian mikrostruktur dijalankan untuk menilai sifat-sifat mekanikal sample sama ada sesuai untuk penggunaanya sebagai mata alat pemotong. Kajian ini juga membolehkan industry untuk memahami cara-cara penghasilan perkakas pemotong mereka sendiri untuk memudahkan proses pemesinan.

ABSTRACT

Ceramic cutting tool are the most commonly used in machining operation especially in dry condition. The advantages of ceramic such as high hot hardness and high refractoriness enable this cutting tool to be applied in machining various hardened steels. The process of producing the cutting tool by using powder technology is a one method that widely used for fabricate a ceramic cutting tool material. In this study, increasing the alumina-based ceramic density is the focuses to improve the performance of properties with four difference pressure it is non CIP, 250 MPa, 300 MPa and 350 MPa using the Cold Isostatic Press (CIP) machine. Therefore, the effect of the CIP profile is investigate to produce end product that have characteristics such as good microstructure, high strength and high density. Spray dried alumina powder was used as a main material to produce the cutting tool. It involves three main methods where the first methods is prepared the raw material of a micrometer and mixed using ball milling about 12 hours. Then the second process, the powder will be pressed using hydraulic press at 5 tons before compressed through CIP at non pressure, 37000 psi, 44000 psi, and 51000 psi. Next process, the green body will be dried and sintered at 1400 °C for 9 hours. The final product that has been produced will be evaluate as ceramic mechanical properties such as relative density measurement, Vickers hardness tests, shrinkage measurement and microstructural studies at the sample either suitable for its use as a cutting tool. This study also allows the industries to understand how to fabricate their own cutting tool for better feasibility in machining.

DEDICATION

This thesis is dedicated to my beloved parents

Adam Bin Mahat and Rasimah Binti Md Jinal

To all my friend, lecture, technician, and supervisor in helping and guiding me throughout the project.

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First and foremost, praise to Allah the Almighty for the strength and hope given to me troughout doing this research. I would like to express my sincere appreciation to my supervisor PM. IR. Dr. Mohd Hadzley Bin Abu Bakar for the guidance, encouragement and patient throughout this FYP project. I would like also to give my gratitude to UTeM lecture and staff who have contributed to the success of this project.

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LIST OF ABBREVIATIONS, SYMBOL AND NOMENCLATURE

Al_2O_3	-	Aluminium Oxide
Cr_2O_3	-	Chromium (III) Ocide
HRA	-	Rockwell A Hardness
SEM	-	Scanning Electron Microscope
YSZ	-	Yttria Stabalized Zirconia
μ	-	Micron
^{o}C	-	Degree Celsius
g	-	gram
M	-	Mega
Mm	-	Milimetre
Min	-	Minute
Pa	-	Pascal
Rev	-	Revolution
Rpm	-	Revolution per minute

CHAPTER 1

INTRODUCTION

This chapter is about the explanations of the background ceramic cutting tools in the difference pressure using CIP and mechanical properties on the fabrication of ceramic cutting tool for this project. The problem statement provides a current situation problem of cutting tool that have in markets. While the objective explains the aim that needs to be achieved, and the scope cover all thing that supposed to do in this project.

1.0 Background of Study

The cutting tool is the one of the major factor that can increase the performances of machining process. There are several type of cutting tool material such as carbon tool steel, high speed steel (HSS), cemented carbide, ceramic, cubic boron nitride (CBN) and diamond. Cutting tool can be categories in two conditions it is single point tool used only one cutting edge such as turning, shaping and planning process. The other one is multipoint tools used in milling and drilling process. There are been used to remove material from work piece by shear deformation. All type of material selected for a particular application depends on the type of machining, material to be machined, quality and quantity of production. Usually, cutting tool materials must be harder than the material to be cut which enable them to withstand the heat generated in the cutting process.

Among many cutting tools that available in industry, ceramic cutting tools being the most dominated especially when dry machining applied. Ceramic cutting tool material is combinations of ceramic powder that are pressed into insert shape under high pressure and sintered at high temperature. There are possessing resistance to corrosion, high compressive strength, and high resistance temperature. Because of these reasons, ceramic materials have been widely used due to its admirable properties especially in high temperature and high speed machining.

One of the major ceramic materials in ceramic matrix composite field is alumina. Alumina, which known as aluminum oxide, is the most popular material to select as fabricate cutting insert because of its excellent hardness, electrical and thermal insulator behavior against the environment and the work piece (Azhar, Mohamad, Ratnam, & Ahmad, 2011) . Therefore, alumina based materials are usually use in refractory (furnace wall), water filter, mixer (ball mill jar), polishing (grinder wheel) and cutting tool insert application. To produce alumina that capable to be applied as cutting tools, raw powders of alumina should be carefully processed. Several steps such ball mill, insert to mold, pressing, and sintering should be controlled in order to produce high density ceramic body with fine and uniform microstructure.

Controlling pressing parameters is one of the main factors to produce perfect cutting tools. There were two processing stage, combining with hand press and cold isostatic press. Both process are important for shaping and decertifying the alumina compact. However Later process, which is CIP contributed to the more significant influence for alumina density. As the alumina powder pressed perfectly, the shrinkage, microstructure and hardness could be increased and promote the alumina compact to be well ready in machining operation.

In this study, the effect by increasing the pressure of compaction will improve the properties of cutting tool. Therefore it is necessary to study the parameter on mechanical properties such as microstructure, density, hardness and dimension before and after sintering of the insert cutting. Finally, the results obtained will be used to design and produce the new ceramic cutting tool and determine the suitable pressure of CIP in alumina-based ceramic cutting tool.

1.2 Problem Statement

Development and advancement ceramic insert cutting tool technology involve basic processes such as mixing, compaction and sintering with various parameters. The better quality and performance of ceramic insert cutting tool is depend on powder composition, pressing pressure, sintering temperature, processing time and grain size of the ceramic powder. However, after the sintering process the mechanical and physical properties of ceramic insert cutting tool will significantly affected the parameter such as hardness, density, strengthens, and dimensional accuracy.

Nowadays, alumina acts as a new alternative ways and widely used as cutting tool for machining process due to their hardness at high temperature and lower reactivity with steel. Unfortunately, alumina based ceramic cutting tool is less toughness thus resulting in a tool failure of premature caused by chipping or breakage (Azhar, Choong, Mohamed, Ratnam, & Ahmad, 2012). Significant improvement has been taken place in the past to enhance ceramic toughness but brittleness properties of ceramic prevented it from being widely used (Azhar, Ratnam, & Ahmad, 2009).One way to improve the toughness of cutting tool is by high densification. In addition, the cost of commercial cutting tool are high that can burden the small medium industry. Therefore, fabrication our own cutting tool is necessary to overcome the high cost and inconsistent performance of the commercial available cutting tool today.

Cold Isostatic Pressing (CIP) is a one of the best-known forming technique to fabricate ceramic product with the complicated shapes by applying a high pressure on the fluid a very homogeneous (Cui, Wang, & Guo, 2018). Typical pressure range that can produce using CIP machine in the range from 100-600 MPa, and the temperature is usually at room temperature. The advantage of cold isostatic pressing compared to uniaxial pressing are smaller density gradient and a stronger densification given to the ceramic product (Cui et al., 2018).It is one of the alternative technique that can improve the densification of ceramic cutting insert with homogenous microstructure by lower apparent porosity. The ceramic powder can reach about 95% of theoretical density during the compressing process.

The purpose of this project is to fabricate alumina-based ceramic cutting tool with the difference pressure (non CIP, 250 MPa, 300 MPa, and 350 MPa) by using CIP machine.

As the ceramic powder will be compacted and sintered. The material properties behavior of cutting tool alumina based ceramic will be evaluated based on microstructure, density, and hardness. In addition, the dimension of alumina-based ceramic cutting tool will be examined before and after sintering. The mechanical and physical properties alumina-based ceramic cutting tool will be evaluated by using scanning electron microscope, electronic densitometer, digital caliper and Rockwell hardness tester. In the end, this result will be used to purpose some improve or refinement for cutting tool development in the future.

1.3 Objective

The specific objectives have been defined for this project, they are:

I. To fabricate the alumina-based ceramic cutting tool using CIP and sintering processes.
II. To evaluate the mechanical and physical properties of this fabricated cutting tool based on hardness, shrinkage dimension and density.
III. To evaluate the microstructure of the cutting tool according to the CIP pressure.

1.4 Scope of Study

In this research, the main purpose is to study on improving densification of fabricating alumina-based ceramic cutting tool by using Cold Isostatic Pressing (CIP) process. The research can be divided into three main scope which including material, processing and mechanical properties. In the material scope, the main raw material been used for ceramic cutting tool are Aluminum Oxide (Al_2O_3) that will be design for lathe machine. The raw material powder will then mixing under ball milling process to obtain the desired size of fine powder. Three parameters will be studied in this research in terms of pressing and compaction. Cold Isostatic Pressing (CIP) pressure for densification process are 250 MPa, 300 MPa and 350 MPa were applied to investigate the effect of different CIP parameter and without using CIP to the alumina-based ceramic cutting tool. The sintering temperature of 1400^{o}C with soaking time 9 hours will apply to the sample. Lastly, the properties will be investigated included mechanical properties such as shrinkage dimension, density, microstructure, and hardness of the cutting insert after the fabrication is done.

CHAPTER 2

LITERATURE REVIEW

On this chapter, it consists of information of this project in order to get the whole fact and data about ceramic material, cutting tool, and lathe machine which will give the overview of a research. In addition, the literature review will presents about related study do by previous research and will be working as a reference. Various references are gathered to gain the information such as journal, book, articles and other source on the internet that may relate to this project.

2.1 CNC Lathe Machine

CNC lathe machine is the one of the famous machine that usually been used in manufacturing industry. Lathe machine can be defined as the removal metal from a workpiece until it produce the shape, size and surface quality of finish product as request. It basically used to hold the cylindrical workpiece that involves the process of removing operations such as turning, facing and boring which rotates at high speeds. According to Helmi and El-Hofy (2011), other several machining process that possible can be done by using lathe machine is drilling, tapping, knurling, tapering, and reaming threading when the suitable cutting tool and attachments are applied on it.

2.1.1 CNC Lathe Components

The primary component of the typical CNC lathe machine at industry shown as Figure 2.1 and Table 2.1.

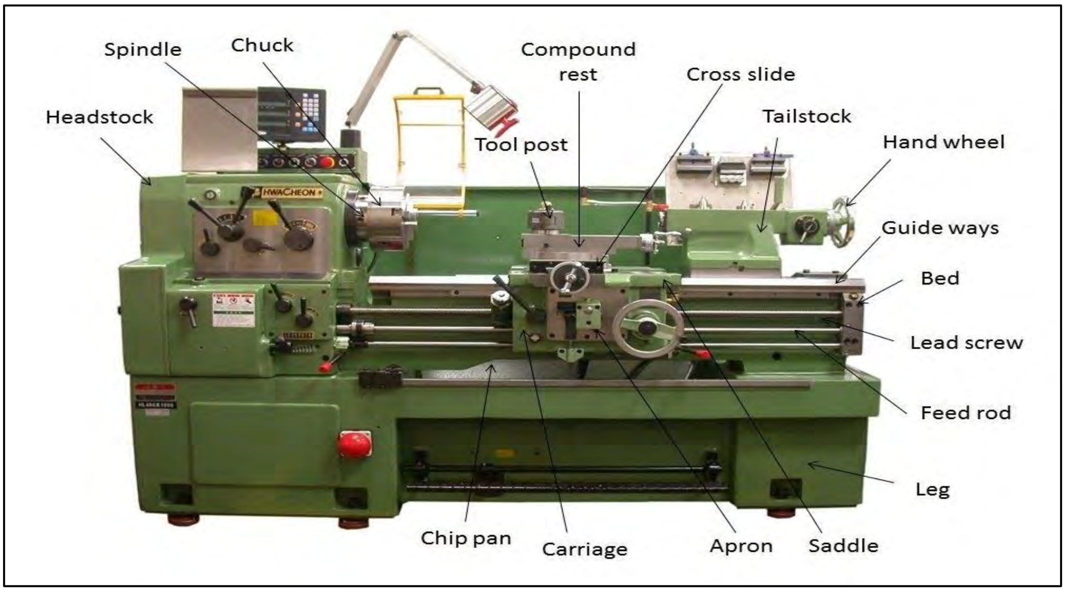

Figure 2. 1 Component of Lathe Machine in Industry

Table 2. 1 Function of Component of Lathe Machine in Industry

Parts	Function
a) Bed	Bed or base is provided to support all main component of the lathe machine
b) Headstock	Headstock is equipped with pulley, belts and motor. It is permanent to the bed
c) Chuck	Chuck or collets act as holding device and help to hold or clamp tubing workpiece.
d) Tailstock	Tailstock is placed at the opposite end lathe machine and be able to slide along the way. It acts as support device to hold and clamped at the end of the workpiece
e) Carriage	Carriage is used to move and carry the cutting tool where also attached to the tool post.
f) Cross slide	Cross slide is able to move radially in and out in order to control the position of the cutting tool.

2.1.2 Cutting Process

Lathe machine is widely used in manufacturing industry due to the various cutting operation and ability to produce many type of cutting shape in order to manufacture products. Figure 2.2 shows several operation that can be done using lathe machine.

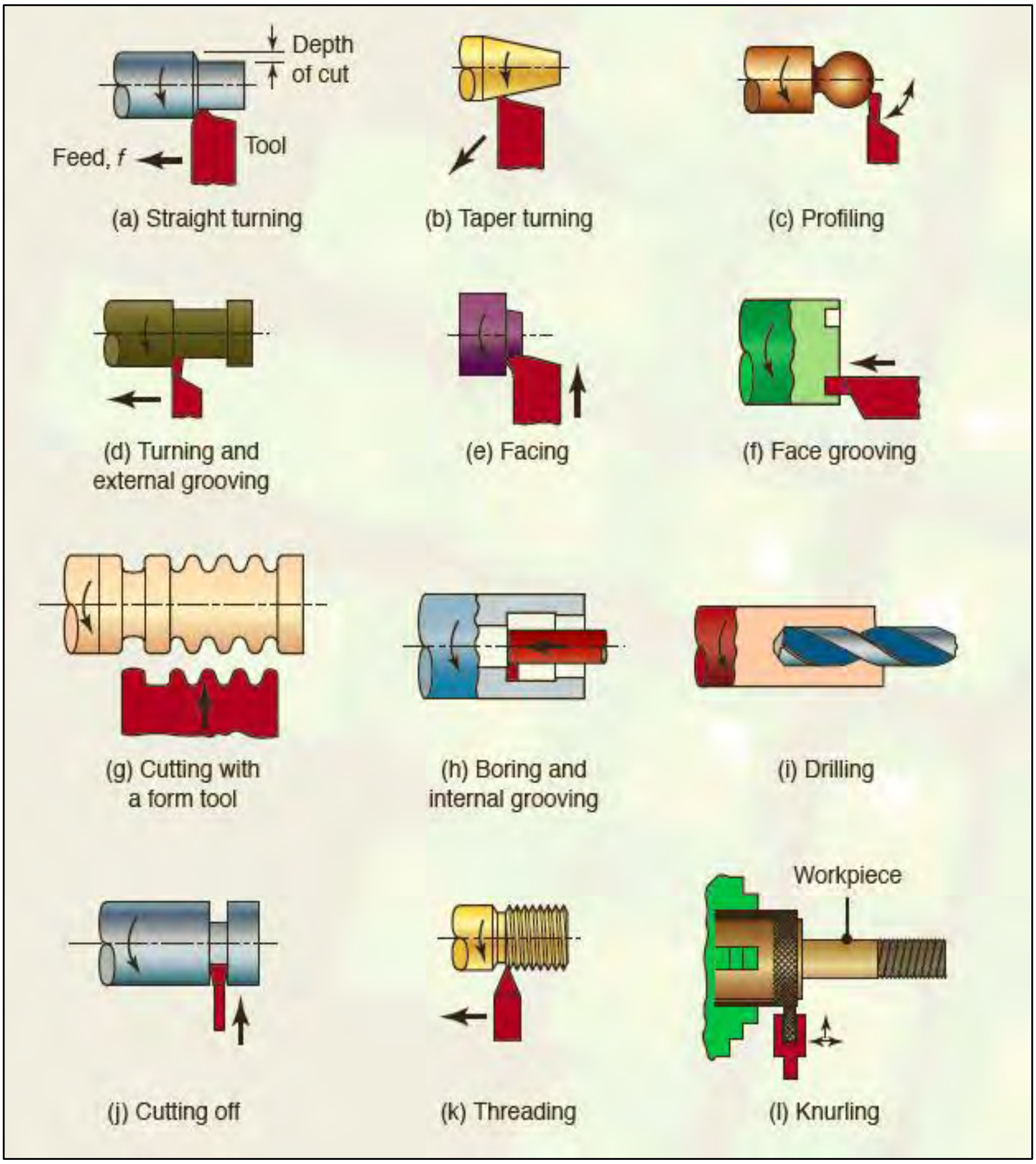

Figure 2. 2 Several Cutting Operation Perform on Lathe Machine (Kalpakjian and Schmid, 2013)

According to Kalpakjian and Schmid (2013):

- **Turning** - A process that create straight, conical, curved or grooved workpieces
- **Facing** - Process of cutting on perpendicular to its axis and create a flat surface at the end of the part
- **Cutting with form tool** – Process that create a various symmetric shapes in conjunction for functional or aesthetic purpose using formed cutting tool
- **Boring** - Process enlarge the existing hole that already made from the previous process
- **Drilling** - Process that create a new hole and may be continued by boring to increase the dimensional accuracy
- **Cutting off** - Remove unwanted part by cutting process
- **Treading** - Process that create a internal and external threads on workpieces
- **Knurling** – Process that create regularly shaped texture on cylindrical surface to make it knob or handle

2.2 Turning Process

Turning is one of cutting process that removing unwanted cylindrical part from a workpiece by using a lathe machine and requires cutting tool, fixture and workpieces. The fixed fixture with the workpiece and attached to the lathe machine which rotates at high speeds. The cutter, also attached to the machine carrier, consists of single point cutting tool and multi-point cutting tool depends on the operation. The main of turning operation usually use a simple single-point cutting tools, with the geometry of a typical right-hand cutting tool (Kalpakjian and Schmid, 2013). There are three common type of turning process which is straight turning, taper turning and transverse turning. Straight turning process happen when the direction of the feed motion is parallel to the turning axis while the taper turning occurring when the direction of the tool feed motion intersects with the turning axis (Cui, Guo, & Zheng, 2016). Meanwhile, tranverse turning can be divided into two type process it is radial and facing turning. The cutting process happen when the direction of the tool feed motion is perpendicular to the turning axis. According to Helmi and El-Hory (2011), the main motion is the rotary motion of the workpiece arround the turning axis, while auxilirary motion is feed motion or the liner motion of the tool.

The first stage to begin the process is the workpiece should be holding or mounting to the machine which is known as work holding device. It capable to mount workpiece to the machine accurately and rigidly secures the workpiece to the machine. During machining process this device will help to withstand the significant forces created (Hoffman et al., 2014).

2.2.1 Tool Geometry

Tool geometry is one of turning parameter that need to be stress out during turning operation. It is so important in order to achieve good surface finish with low cost at high productivity. According to Kalpakijian and Schmid (2013), the various angles in a single-point cutting tool plays a significant function in machining operation. The angles of cutting tool will be measured in a coordinate system that consist three major axes of the tool shank. However, these angles may be different with regard of the workpiece, after the tool is installed in the tool holder. There are about five types of the angle influence in the geometric tool.

Table 2. 2 Type of Angle in the Geometric Tool

Angle Type	Function
1. Rake Angle	Rake Angle will control direction of chips flow and the strength of the tool tip. It has two direction in each rake angle it is positive and negative direction. For the positive rake angle it can increses tool life cause by minimize cutting force and temperature. Notheless, positive rake angle may possibly cause premature tool chipping and failure to the cutting tool with low toughness. (Kalpakjian, 2013).
2. Side Rake Angle	It generally control the direction of chip flow. The rake face can be difened by two angle which are side rake angle and back rake angle. The angle typically in range from - 5° to 5 °. (Kalpakjian, 2013)