ABSTRAK

Grafit telah banyak digunakan dalam bentuk pelbagai funsgsi di dalam proses pembuatan. Ianya merupakan satu bahan yang unik yang membolehkannya untuk dimanipulasikan mengikut kehendak. Walaubagaimanpun, grafit merupakan satu bahan yang kasar yang perlu permesinan kering Jesteru, bahan ini perlu diproses menggunakan teknik process khas seperti RUAM proses. Objektif utama dalam pemesinan adalah untuk menghasilkan permukaan produk yang licin. Kajian dilakukan dengan mengkaji parameter pemesinan seperti kelajuan pemotongan, kadar suapan, kedalaman pemotogan, kekerapan dan amplitud dan kesannya terhadap prestasi pemesinan (kekasaran permukaan dan daya permotongan) untuk meghasilkan kombinasi parameter yang terbaik dalam mencapai prestasi pemesinan yang paling baik terdasarkan pelbagai objektif. Untuk memulakan eksperimen, Box Bechken Design dipilih melalui Response Surface Metodology (RSM). Ianya mengeluarkan 46 eksperimen. Seterusnya, model matematik bagi setiap tindak balas dibangunkan Kecukupan model dianalisis secara statistic menggunakan ANOVA. Pelbagai plot diagnostik dinilai untuk memeriksa keberkesanan model. Pengoptimuman dengan pelbagai objektif dilakukan melalui pengoptimunan berangka dan keptusan disahkan. Kesilapan kurang daripada 20% menunjukan itu adalah penyelesaian terbaik. Pencarian membuktikan bahawa kekasaran permukaan sensitif terhadap kelajuan permotongan, dan kadar suapan,manakala daya pemotongan sensitif terhadap kelajuan permotongan, kadar suapan dan kedalaman pemotongan. Kekerapan dan amplitud turut memberi impak posif walapon tidak besar. Oleh itu, kombinasi parameter yang paling optimum ialah apabila kelajuan pemotongan tinggi, kadar suapan rendah, kedalaman pemotongan rendah, kekerpan tinggi dan amplitud tinggi.

ABSTRACT

Graphite has been widely used in a variety of applications of manufacturing processes. It is materials that have unique properties that allows it to be manipulated to form into various types to satisfy a research and industrial interest. However, graphite is an abrasive material that needs to be machined dry and thus, requires special machining techniques such as Rotary Ultrasonic Assisted Milling (RUAM) process. Smooth machined surface has been always the objective when machining this material. The present work aim to optimize the RUAM machining parameters (cutting speed, feed rate, depth of cut, amplitude and frequency) for effectively machining graphite material. A Box Behnken Design is chosen through Response Surface Methodology (RSM) has been used with the designof experiment with totals of 46 runs. Models are analyzed statically using analysis of variance (ANOVA) to determine significant parameters and possible interactions. Various diagnostic plots were analyzed to check the model effectiveness. Multi objectives optimization is performed through numerical optimization and predicted results are validated. The percentage error is less than 20% thus the solution is consider optimal run condition. The finding determine that surface roughness is sensitive toward cutting speed and feed rate while cutting force is sensitive toward cutting speed, feed rate and depth of cut. Frequency and amplitude give small but improving results towards this research. Therefore, the most optimum combination of parameters is when the cutting speed is high, low feed rate, low depth of cut, high frequency and high amplitude.

DEDICATION

This thesis is dedicated to my loving and supportive parents, Othman bin Rahim and Rosilah binti Kasim who has always encourage me throughout my study. I also want to dedicated it to my borther and sister-in-law, Mohd Taufiq Khair bin Othman and Seri Norashikin binti S.Yahap for always being by my side. Finally, this thesis is dedicated to all those who believe in the richness of learning.

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CHAPTER 1

INTRODUCTION

This chapter describes the introduction of the research and briefly explains the problem statements and objectives in the research. The scope and the outline of the research are fully described in this chapter.

1.1 Background

Graphite is a composite material that is basically a crystalline form of carbon, a semimetal that is the most stable form of carbon under standard conditions. It has been widely used in a variety of applications of manufacturing processes. It has unique properties that allow it to be manipulated into various types to satisfy a research and industrial interest. Among its popular applications in industries are in automotive, aerospace, nuclear, electrical industries and many more. Graphite composites have been highly utilized in automotive and aerospace industries because of the unique property of high strength yet lightweight at the same time. In aerospace industry, graphite/epoxy composites have been commonly used in aircraft component such as rudders, vertical tail fin skins and horizontal stabilizer skins due to the same properties.

Several papers have also reported on the ability of graphite to works in nuclear application. Burchell,(n.d.)stated that graphite is an excellent material for a solid moderator in nuclear reactor application due to the fact that graphite has high thermal and electrical conductivity and also low absorption of X-rays and neutrons. It also has high electrical conductivity which makes it common to be used in manufacture of carbon brushes in electrical application.

However, although graphite has various functions, it has been proven that the uniqueness of its properties can cause challenge in machining process. Properties of graphite show that graphite materials are hard to machine because of its greater brittleness and hardness (Rosenthal et al. 1964). It has characteristics such as tear resistance and abrasion strength. Because of the abrasiveness, it may cause fast tool wear especially on metallic uncoated tools.

Not forgetting another unique property of graphite is that the composite is brittle and must be machined dry. This property automatically making the material not suitable for most conventional machining methods. Most conventional machining methods use coolant fluids in its machining process. Graphite however, must always be machined dry because of its dust and chips. Any moisture or water when working with graphite will produce abrasive slurry as the coolant combines with fine bits of graphite chips and dust. This abrasive slurry will greatly impact the tool life (tool wear). Therefore, uses of liquid coolant are forbidden. If the raw graphite has been stored or soaked in water, it should be baked first at 300-400°F to drive out any excessive moisture. Furthermore, operating machining operations without the use of any cutting fluids is actually a goal that has tried for in industry due to the ecological and human health concerns caused by the cutting fluid (Sreejith and Ngoi, 2000; Diniz and Micaroni, 2002).

The needs for methods of machining this type of material have led to the introduction of special machining techniques like ultrasonic machining (USM). Ultrasonic machining is a non-conventional machining method that commonly has low material removal rates, generally designed for cutting non-conductive and brittle materials such as engineering ceramics. USM does not thermally damage the workpiece material, which is important for the quality of brittle material product. USM removed material primarily by repeated impact of the abrasive particles, and the material removal rate (MRR) and surface integrity are influenced by various factors including the material parameters of the workpiece materials.

Rotary ultrasonic machining (RUM) is then invented to overcome the shortcoming of USM. It is a hybrid machining process that combine material removal mechanism of USM and diamond grinding. It is specially designed for brittle and hard materials. According to Pei et al. (1995), rotary ultrasonic machining (RUM) is the most suitable process for high material removal rate while having low machining pressure and caused less damage on surface, which make it suitable to machine materials with the properties such as graphite. It is proved that application of ultrasonic enable to decrease cutting forces making it suitable machining thin-walled workpiece, and also decrease generation of heat which allows it to machined sensitive materials (Marcel, Marek, & Jozef, 2014). Moreover, it is proven to increase tool life.

But unfortunately rotary ultrasonic machining is limited to machine circular holes or cavities due to the rotary motion of the tool. Many attempts have been made by other researchers in attempt to used ultrasonic machining process to machine flat surfaces or milling slots (Pei et al. 1995). The unique characteristic of this vibration assisted machining is that it can be combine together with conventional machining methods, which in this study is milling process.

Rotary ultrasonic assisted milling (RUAM) has been investigated in a few studies, experimenting on different materials. Marcel et al., (2014) studied on the RUAM process on aluminium alloy while Kuo & Tsao, (2012) investigated the RUAM process on brittle material such as glass and ceramic. However, no reported journal has been found on machining graphite using the machining process. It has been proven by other researchers using different materials; RUAM can improve the quality of surface finish and also increase the tool life of cutting tool.

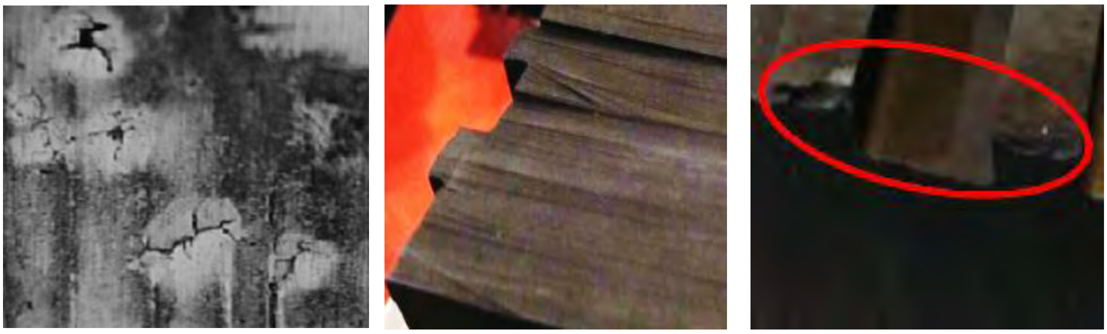

Figure 1.1: Damaged surface on graphite material

Figure 1.1 shows the cracks, rough surface finish and chipping that happened on graphite when non appropriate methods are chosen. These effects can cause the quality of graphite workpiece to drop significantly. Milling process is the basic machining process to produce a well surface finished workpiece and is most commonly used for material removal process in industry(Yang et al., 2009).however, by using only milling process, the surface finish of graphite could be compromised. Nevertheless, by sing RUAM machining process, no secondary process needed as most conventional machining methods require more process to get the desirable surface finish. Therefore, rotary ultrasonic assisted milling process may lower the cost and process needed to produce good quality surface finish for graphite. Increasing the tool life is also need to be proven as normal milling process dramatically reducing the tool life of cutting tools.

1.2 Problem Statement

Graphite material is known for being brittle. This characteristic of graphite has cause the machining of this material to be very difficult which, directly related on the suitable cutting parameter. Using wrong parameter combination can cause cracks, chipping and rough surface finish onto the material that can lead to part rejection.

Since the material has to be machined dry, the machining of graphite will leads to high friction between the cutting tool and workpiece. This can results in high temperatures that can impair the dimensional accuracy and the surface quality of the products (Yang et al., 2009). Because of this, controlling the force is important in graphite machining.

Thus, a more suitable technique are prepared to deal with the description of this material. One of the suitable techniques are by combining the ultrasonic frequency with the conventional milling operation.

1.3 Objectives

Based on the challenges encountered in conventional machining process of material graphite, this project embarks on the following objectives:

- To analyse the effects of rotary ultrasonic assisted milling parameters (cutting speed, feed rate, depth of cut, frequency and amplitude) on machining performance.
- To identify the best combination of cutting parameter to achieve optimum machining of graphite materials by using ultrasonic assisted milling process.
- To validate the effectiveness of the proposed optimize parameter.

1.4 Scope

In order to achieve the research objectives and to plan the research procedure framework, the scopes of this study have to be predetermined. The machining parameters for graphite that are to be studied in the objectives will be obtained from the following;

- Graphite EDM POCO 160
- Milling process(cutting speed, feed rate, depth of cut)
- Rotary ultrasonic system (frequency, amplitude)
- Machining force analysis
- Surface roughness analysis

1.5 Summary

Chapter 1 introduce the project which include the background, problem statements, objectives and scopes. This chapter describe the experiment of using rotary ultrasonic assisted milling on machining graphite. Problem statement has been explained where surface roughness and tool wear are the conditions that want to be investigate. The objectives need to be achieved towards the end of the project.

Chapter 2 presents the relevant literatures on machining graphite using related machining process. They includes the definition of graphite, graphite making process, existing methods and model for the analysis of machining graphite, related milling and ultrasonic machining process, factors and parameters that affect machining of graphite and techniques for machining graphite. The purpose of reviewing these topics is to provide a theoretical base for the remainder of this research.

Chapter 3 shows the methodology of this research which includes details properties of the workpiece, experimental equipment and measurement, machining tool specification and experimental setup. The design used in this research is also explained in this chapter. The experimental design presented in this chapter includes the statistical method used for this research for optimization of machining graphite.

Chapter 4 discusses the result and data analysis for finding the best combination of parameter on machining graphite. The data are presented and discussed in three parts. Part one discussed about the experimental results of surface roughness and cutting forces. Part two shows the data analysis using the data generated on statistical method, which analysed both surface roughness and cutting force. Last but not least, part three discussed the optimization process which the data is generated from Design Expert. Lastly, validation result is presented and the amount of bas error between the selected optimization values as experimental results are discussed.

The research is conclude with a summary of experimental results and suggestion for future work in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

The literature review was carried out with the attention to attain the objectives of this project. It consists of the facts associated with compacted graphite material, milling machine, rotary ultrasonic system, machining parameters and cutting tools. All the facts on this chapter served as a reference and guidelines for this study.

2.1 Graphite

Graphite has been form into various types and conditions to match with its design functions. Graphite that is used in most industrial applications is synthetic graphite. Synthetic graphite is the crystalline form of carbon and is man-made material. It is commonly known for its resistant to high temperatures and acidic or basic solutions. Specific properties can be obtained by engineering graphite such as density, hardness, electrical resistance, porosity, compressive strength, flexural strength, coefficient of thermal expansion and thermal conductivity.

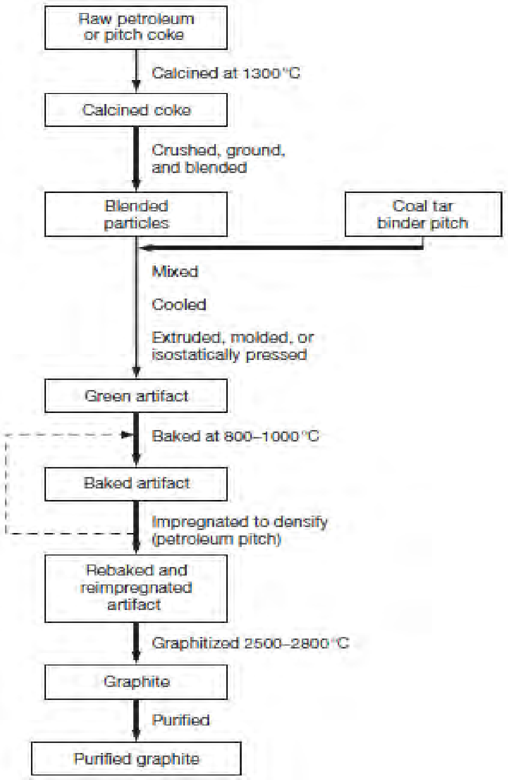

Figure 2.1: major processing steps in producing synthetic graphite.

Figure 2.1 shows the major processing steps in producing synthetic graphite. According to Semicocarbon (2016), typically graphite is produced from petroleum coke which is heated to incandescence, which drives off many volatiles. The coke is then crushed and ground to specific particle sizes dictated by the final grade. The coke powder is mixed with coal tar pitch and other additives which act as a binder. This mixture can be extruded or molded into desired blocks and rounds. There are various methods of producing synthetic graphite shapes such as extrusion, compression molding and isostatic molding.

Once the "Green" or raw carbon blocks are molded they undergo an extended baking cycle to convert the pitch into solid carbon. Once the baking cycle is complete the "Baked Carbon" is ready for the final process of graphitization. The conversion to graphite from baked carbon takes extremely high temperature, which normally at 5,000 degrees Fahrenheit or higher. This temperature is typically reached in a controlled atmosphere induction furnace. An added benefit of the extremely high temperature is the expulsion of most of the impurities.

The final result of this graphitization process is a solid graphite block or round made up of graphite particles that held together by the converted binder. Graphite is supplied in various raw block sizes, some as large as 24” x 24” x 72 (Edm, n.d.). The attributes of the graphite are managed by the formula utilized which will determine the particle size, sort of coke, last porosity, added substances, and method of molding.

According to Burchell, (n.d.), synthetic graphite is a really astounding material whose one of a kind properties have their beginnings in the material's complex microstructure. The bond anisotropy of the graphite single crystal (in-plane strong covalent bonds and weak interplanar van der Waals bonds) joined with the numerous possible structure varieties, which together constitute the material's "texture," make manufactured graphite a particularly tailorable material. However, according to AZoM (2014), synthetic graphite has a tendency to have higher porosity, lower density and higher electrical resistance. The increased porosity makes it unsuited for the refractory applications.

Next is the most common combinations of graphite material which is compacted graphite iron (CGI). CGI appears to be the alternative option for grey cast iron (GCI). According to Gabaldo et al, (2010), compacted graphite iron has characteristics of heat conductivity and damping similar to grey cast iron, but with superb mechanical properties. Since CGI has higher mechanical strength than GCI, it can provide a great advantage in the manufacture on engine block and heads. However, CGI is known to have poor machinability compared to GCI. This may due to the fact that the main component of the material is graphite. This results in higher cutting tool wear and loss in productivity (Da Silva, Naves, De Melo, De Andrade, & Guesser, 2011).

A few researches has been done on machining this material. A research done by Su, Guo, Song, & Tao (2016) stated the difficulty to machine CGI. Although it is suitable for high strength part, but due to lack lubrication, low material thermal conductivity, casting crust with ferrite structure, and internal hard titanium particles, machining CGI is very difficult.

Dawson and Indra (2007) stated that the application of Compacted Graphite Iron (CGI) provides approximately double the fatigue limit of conventional grey iron and aluminium alloys. In comparison to aluminium, the mechanical properties of CGI benefits in; higher specific performance, reduced cylinder bore distortion, improve oil consumption, lower production cost and increase recyclability

The improved mechanical properties of Compacted Graphite Iron relative to grey iron and aluminium provide many contributions to the design and performance of internal combustion engines for passenger and commercial vehicles. In form of forming cylinder blocks, CGI cylinder block will be heavier than a similar displacement aluminium block due to the density. However, because of the higher strength and stiffness of CGI, the main bearing thickness can be reduced to provide a significantly shorter cylinder block (Dawson & Indra, 2007).

2.1.1 Application of Graphite

The use of graphite in the industries is countless. It has been used in uncountable applications, from electrical to nuclear application. It has unique properties that allow it to be controlled and manipulated into various function. Figure 2.2 shows the application of graphite in related fields.

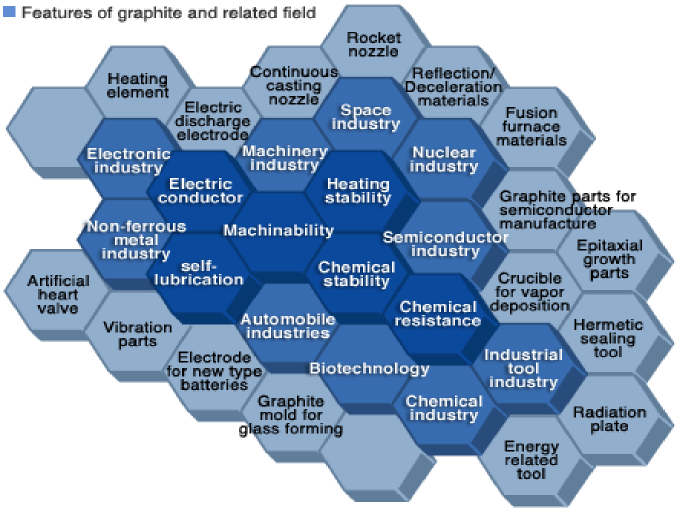

Figure 2.2: Application of graphite (Joe Thompson, 2017)

For example, graphite composites are highly utilized in automotive and aerospace applications because of their lightweight yet high strength properties. (Li et al., n.d.) It may seem unlikely, but graphite is used for a wide variety of applications in aerospace industry. Generally, it is used as engineered material to produce precise machined plates, posts, nuts and bolts along with heating elements and fixtures used in heat treatment of aerospace metals. The graphite plates are preferred as fixtures because they are inert and do not transfer any chemistry or metals to the aerospace metal being treated (Semcocarbon, 2016) Graphite also used as a mold to cast titanium, aluminium and stainless steel to near net shapes. Graphite itself is used for jet and rocket engine nozzles, impellers and rotors move aviation fuel safely without the dangers of creating sparks to ignite fuel.

Both article from Burchell (n.d.) and AZoM et al. (2014) stated that graphite is used for production of nuclear moderator in nuclear application because of its low neutron absorption, high neutron moderating efficiency, its resistance to radiation damage, high thermal conductivity and high strength at temperature. The biggest applications of nuclear graphite include its use as moderator and in the fuel form of many thermal reactor designs.

In the production of iron, graphite blocks are used to form part of the lining of the blast furnace. Its structural strength at temperature, thermal shock resistance, high thermal conductivity, low thermal expansion and good chemical resistance are of paramount importance in this application. The electrodes used in many electrical metallurgical furnaces are manufactured from graphite such as the electric arc furnaces used for processing steel.

According to Yang et al., (2009), high purity graphite has been highly used for semiconductor manufacturing processes. Furthermore, this type of graphite must be high thermal and chemical resistance, great resistance to the temperature change, good electrical conductivity and increase strength with higher temperature (Sglcarbon, 2000). High-purity graphite components have been adopted in various applications in semiconductor manufacturing processes such as ion implantation, plasma etching, and electron beam evaporation.

Other than that, graphite also has been the majority choice for the material used in EDM electrodes today in the United States as stated by Mercer (2004). Graphite has many advantages that have made it the material most widely used for EDM electrodes. Among of it, it can be made in large blocks. It also has low coefficient of thermal expansion, which is three times lower than copper. This will guarantee the stability of electrode geometry during EDM. It also has density five times lower than copper, which results in lighter electrodes.

Due to its high temperature stability and chemical inertness graphite is a good candidate for a refractory material. It is used in the production of refractory bricks and in the production of “Mag-carbon” refractory bricks (Mg-C.) Graphite is also used to manufacture crucibles, ladles and moulds for containing molten metals. Additionally graphite is one of the most common materials used in the production of functional refractories for the continuous casting of steel. In this application graphite flake is mixed with alumina and zirconia and then is statically pressed to form components such as stopper rods, subentry nozzles and ladle shrouds used in both regulating flow of molten steel and protecting against oxidation. This type of material may also be used as shielding for pyrometers.

Last but not least, graphite is also widely used in electrical application due to its high electrical conductivity properties. This makes graphite widely used as an electrical material is in the manufacture of carbon brushes in electric motors. In this application the performance and lifetime of the component is very dependent on grade and structure.

2.1.2 Machining Graphite

Graphite machining can be quite tough. Cutting graphite or carbon is different from cutting metals. Cutting graphite requires much less energy and generates much less heat than in cutting metals. Table 2.1 below shows the few journals recorded on machining of graphite.

Table 2.1: Journals on machining graphite

Process	Report	Title
Milling	(Da Silva et al., 2011)	Analysis of wear of cemented carbide cutting tools during milling operation of grey iron and compacted graphite iron
	(Gabaldo et al., 2010)	Performance of Carbide and Ceramic Tools in the Milling of Compact Graphite Iron-CGI
	(Yang et al., 2009)	Optimization of dry machining parameters for high-purity graphite in end milling process via design of experiments methods
Rotary ultrasonic machining	(Li et al., n.d.)	Experimental Study on Rotary Ultrasonic Machining of Graphite/ Epoxy Panel.
Laser-assisted machining	(Skvarenina & Shin, 2006)	Laser-assisted machining of compacted graphite iron.
Turning	(Su et al., 2016)	Effects of high-pressure cutting fluid with different jetting paths on tool wear in cutting compacted graphite iron
Conventional machining	(Abele, Sahm, & Schulz, n.d.)	Wear mechanism when machining compacted graphite iron

Several papers have been reported studies on machining graphite. Research reported by Yang et al. (2009) investigated on the optimisation of cutting parameter of dry machining of high-purity graphite. Based on the research, dry machining is highly recommended as the powder dust of chips may pollute the machines if mixed with coolant fluid. This researches is supported by a few other journals that experimented using dry machining methods, among its are Da Silva et al. (2011), Cong et al (2013), Su et al. (2016).

According to *EDM Today* (2003), graphite must be machined dry at all times without the use of liquid coolants. Coolants is not compatible when machining graphite as the use of coolants will produce an abrasive slurry the slurry happens when coolant combines with the fine bits of graphite chips and dust. The coolant will be able to damage the material as it has open porosity. Essentially the graphite will act as a sponge, as capillary action draws the coolant into the open pores. This contamination will cause problems when the graphite is used in an application that requires the inert nature of the graphite material.