AN INVESTIGATION ON THE EFFECTS OF AL_2O_3 NANOLUBRICATION SYSTEM WITH SURFACTANT ON TOOL WEAR AND SURFACE ROUGHNESS IN TURNING PROCESS

by

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LIST OF ABBREVIATIONS

Al_2O_3	Aluminum oxide
CeO_2	Cerium dioxide
CNC	Computer Numerical Control
CNT	Carbon Nano Tube
CVD	Chemical Vapor Deposition
Cp	Centipose
MoS_2	Molybdenum disulfide
MQL	Minimum Quantity Lubricant
MWF	Metal Working Fluids
OA	Orthogonal array
PCD	Polycrystalline Diamond
PCBN	Polycrystalline Cubic Boron Nitride
PVP	Poly Vinyl Pyrrolidone
SDBS	Sodium Dodecyl Benzene Sulfonate
SDS	Sodium Dodecyl Sulfate
SiO_2	Silicon oxide
S/N	Signal to noise
TiC	Titanium carbide
TiN	Titanium nitrade

Kajian mengenai kesan cecair nano Al2O3 dan pelarut terhadap kehausan mata alat dan permukaan potongan semasa operasi permesinan

ABSTRAK

Aplikasi cecair nano menyumbang kepada peningkatan kualiti permesinan yang terhasil daripada pergerakkan jutaan partikel nano dalam bentuk bebola diantara kawasan pemotongan. Kesan ini mengurangkan geseran, mencantikkan permukaan potongan serta memanjangkan hayat mata alat. Gabungan cecair nano dengan sistem minimum quantity lubricant (MQL) mengurangkan penggunaan cecair sekaligus mengurangkan pencemaran alam. Cecair nano juga dapat menjimatkan kos serta selamat digunakan. Walau bagaimanapun, keberkesanan cecair nano dihadkan oleh mendapan partikel nano. Pengunaan pelarut menyelesaikan masalah mendapan partikel nano. Tetapi, kekurangan kajian disebalik kecekapan cecair nano dengan pelarut menghadkan pengetahuan tentang kesannya terhadap kualiti permesinan. Untuk mengkaji keberkesanan cecair nano aluminum oxide (Al_2O_3) dengan pelarut Sodium Dodecylbenzene Sulfonate (SDBS), satu uji kaji telah dilakukan terhadap proses permesinan aloi titanium, Ti-6AL-4V. Untuk kesan yang terbaik, cecair nano disalurkan menggunakan sistem MQL dimana penyebaran cecair nano kekawasan pemotongan akan lebih efektif. Tiga eksperimen telah dirancang dan dijalankan. Eksperimen pertama bertujuan mengkaji kesan pelarut terhadap kestabilan cecair nano. Keberkesanan cecair nano tersebut kemudian diuji terhadap proses permesinan berbanding sistem penyejukan yang lain (permesinan tanpa cecair pemotongan, permesinan dengan cecair pemotongan, cecair pemotongan dengan sistem MQL dan cecair nano dengan sistem MQL). Eksperimen terakhir dijalankan untuk mengenalpasti kesan pembolehubah; jumlah partikel nano, kelajuan potongan, kadar suapan dan posisi darjah nozel terhadap kualiti permesinan serta untuk menyarankan kombinasi tetapan untuk keputusan optimum. Dalam eksperimen ini, teknik gabungan Taguchi dan Grey Relational Analisis digunakan. Keputusan eksperimen pertama menunjukkan cecair nano dengan kuantiti SDBS sebanyak 1% menghasilkan cecair nano yang stabil. Eksperimen kedua menunjukkan gabungan cecair nano dan SDBS dapat meningkatkan kualiti potongan sebanyak 7.01 %, pemanjagan hayat mata alat sebanyak 10.76 % dan pengurangan tenaga elektrik sebanyak 2.8 % berbanding teknik lain. Eksperimen ketiga menyarankan penggunaan partikel nano (N.C) sebanyak 0.4 %, kelajuan potongan (v) 85 m/min, kadar suapan (f) 0.1 mm/rev dan darjah nozel (N.A) 30^{o} untuk permukaan potongan yang terbaik. Pembolehubah yang disarankan untuk pemanjagan hayat mata alat adalah (N.C) 0.6 %, (v) 85 m/min, (f) 0.1 mm/rev dan (N.A) 60^{o}. Manakala kombinasi pembolehubah untuk penggunaan tenaga elektrik yang terbaik adalah seperti berikut; (N.C) 0.4 %, (v) 75 m/min, (f) 0.1 mm/rev, dan (N.A) 60^{o}. Analisis Grey menyarankan kombinasi pembolehubah yang merangkumi (N.C) 0.6 %, (v) 85 m/min, (f) 0.1 mm/rev dan (N.A) 60^{o} untuk keputusan optimum bagi ketiga-tiga keputusan permesinan.

An investigation on the effects of Al2O3 nanolubrication system with surfactant on tool wear and surface roughness in turning process

ABSTRACT

Application of nanolubricants can improve machining performance since the rolling action of billions of nanoparticles at the tool-chip interface leads to less friction; which can produce superior surface quality and longer tool life. The combination of nanolubricants with minimum quantity lubricant (MQL) systems in machining, minimize the consumption of lubrication oil; consequently, less pollution will be caused. Nanolubricants is a lubrication alternative to improve machining output, a cost saving and less harmful cutting lubricant to human and nature. However, the superiority of nanolubricants is limited, due to the agglomeration of nanoparticles, which leads to sedimentation of nanoparticles after a period of time. The addition of a surfactant can lower the agglomeration of nanoparticles and stabilize the nanolubricants for a longer period. But, lack of study on the performance of nanolubricants with surfactant restricted the fundamental understanding on their effect on mechanics of machining process. Hence, to investigate the effectiveness of aluminum oxide (Al_2O_3) nanolubricants with Sodium Dodecylbenzene Sulfonate (SDBS) surfactant, experimental investigations have been attempted in this study while machining titanium alloy, Ti-6AL-4V. For a better penetration of nanoparticles into cutting region, nanolubricants was supplied with MQL system. Three main experiments were planned and carried out. First stage experiment was mainly to observe the reaction of surfactant (SDBS, Tween 20 and Tween 80) in reducing agglomeration of nanoparticles in nanolubricants. Following that, the performance of nanolubricants in terms of surface roughness, tool wear and power consumption was compared through different coolant approaches (Dry, Flood, MQL (Base oil), MQL (Nano Lub), MQL (Nano Lub + SDBS)). The third stage experimentation was conducted to identify the effect of controlled parameters; i.e.; nanoparticles concentration, cutting speed, feed rate and nozzle angle on the machining performance and also to suggest parameter combination for optimum conditions. In this experiment, a combination of Taguchi and Grey Relational Analysis were employed in order to yield a single parameter combination. The results from first stage experiment showed that nanolubricants with 1 % of SDBS surfactant promote the best nanolubricants stability. Second stage experiment revealed that nanolubricants with SDBS improves surface finish by 7.01 %, tool wear by 10.76 % and power consumption by 2.8 % as compared to other coolant approach. The third stage experiment suggested that a combination of 0.4 % nanoparticles concentration (N.C), cutting speed (v) of 85 m/min, feed rate (f) of 0.1 mm/rev and nozzle angle (N.A) of 30º were the optimum setting for better surface roughness. To achieve minimal tool wear, N.C need to be set at 0.6 %, v at 85 m/min, f at 0.1 mm/rev and N.A at 60º. Finally, minimal power consumption can be obtained at N.C of 0.4 %, v of 75 m/min, f of 0.1 mm/rev and 60º of N.A. GRA suggested a combination of 0.6 % N.C, v of 85 m/min, f of 0.1 mm/rev and N.A of 60º as optimum setting for all the three machining output.

CHAPTER 1

INTRODUCTION

1.1 Research background

The main function of lubrication system in the metal machining process is to serve as a coolant as well as lubricant. It is generally agreed that the application of cutting fluids can improve tool life and results in a excellent surface finish by reducing thermal distortion and flushing away of machined chips. The goals in all conventional metal-removal operations are to increase productivity and reduce costs by machining at the maximum practical speed along with long tool life, low power consumption, fewest reject, lowest downtime, and with satisfactory accuracy and tolerance (Debnath, Reddy, & Yi, 2014).

However, excess of lubrication in machining process increase machining cost, harm humanity and pollute the nature. Current environmental and health concerns, impose manufacturers to reduce the volume of coolant waste. Moreover, repeated use of cutting lubricant induced chemical changes of cutting fluids, which can cause skin disease. In addition, the growth of bacteria and yeast impel environmental hazard and reduces the effectiveness of the cutting fluids (Priarone et al., 2014; Padmini et al., 2016)

It has been reported that the cutting fluids consumed by manufacturing companies accounts; approximately 38 million metric tonnes of lubricants; and it is projected to rise about 1.2 % for every ten years. Estimated cost of cutting fluids, including purchasing, preparation, maintenance and the disposal are about 7-17 % of the total machining costs of a single product (Lawal et al., 2013; Najiha et al., 2016).

Due to the aforementioned challenges and limitation, nanolubricants is some of the alternatives being explored in an attempt to replace conventional cutting fluids. In the present modern manufacturing era, nanointegrated manufacturing has earned wide impetus to grant sustainability and result in ecologically harmless engineering processes (Wang et al., 2009). Nanolubricants is a kind of new engineering material consisting of nanometer-sized particles dispersed in ordinary heat transfer fluids such as water, glycol and oil base fluid. Metal, metal oxides, ceramics and non-metals such as carbon nano tubes and graphene are the most common type of nanoparticles (Saleh et al., 2014).

Capability of nanolubricants to reduce friction, cutting forces, improving surface roughness, prevent workpiece burning and transfer heat effectively makes this fluid well-suited for machining purpose. The nano-size of particles makes it easy to slide over into the cutting area and produce rolling effect. This rolling effect works as a ball-bearing function which reduced direct metal contact, hence lessen friction and heat generation (M. Sayuti et al., 2012). Besides, it was found that the thermal conductivity of nanolubricants increases almost linearly with nanoparticles concentration, which produces hydrodynamic interactions that enhance thermal transport ability (Padmini et al., 2016). Nanolubricants also can facilitate costs reduction, improve health hazard and environmental performance of the machining process.

Application of nanolubricants has widely spread into many important fields such as electronics, transportation, medicine, heating, ventilating and air-conditioning. However, agglomeration of nanoparticles limits the superiority of nanolubricants. Due to the high surface energy of nanoparticles, it is easy for nanoparticles to coagulate and difficult to disperse in the base fluid. These reactions cause sedimentation of nanoparticles, which makes nanolubricants unstable and ineffective. This phenomenon is affected by numerous factors which include size of particles, characteristic of particles, lubricant viscosity, bonding force between particles and gravitational force (Kedzierski, 2013).

One of the solutions used to alleviate this issue is through addition of an additive known as surfactants. A surfactant which stands for "surface acting agent" is known as a compound that lowers the surface tension of a liquid, increases the contact between the liquid and another substance. This additive can interact with the surface of a liquid to change its properties. Mechanism used is known as adsorption, which will accrete on the surface of the liquid, creating a film that reduces its surface tension. Research in the area of nanolubricants stability have proved that the usage of surfactant makes nanolubricants stable (Chen et al, 2013; Nabel A. Negm, Satish V. Kailas & Pottirayil, 2014). Typically, surfactant is divided into three groups, which are anionic, non-ionic and cationic. Very often, the selection of surfactant type is made based on the function required. Some of the surfactants used by researchers are sodium dodecylbenzene sulfonate (SDBS), Tween 20, Tween 80, alkyl benzene sulfonates, CTAB and Span-80.

At present nanolubricants is channelled through minimum quantity lubricant (MQL) system for machining application. This new concept is eco-friendly as the machining output is enhanced at a very low consumption of lubricant. MQL is a system which transfers lubricant into the cutting area or zone in a small amount of oil mist estimated between 10-100 ml/hr. MQL offers the use of very small amounts of metal working fluid (MWF) that is approximately 10,000 times less than the conventional flood cooling. MQL technique consists of a mixture of drops of cutting fluids (neat oils or emulsions) in a flow of compressed air, generating a "spray" which directed to the cutting region of work as a lubricant and coolant (Kalita et al., 2012; Hadad & Sadeghi, 2013; Silva et al., 2013).

1.2 Problem statement

To fulfill the current industrial demands of a good quality product with minimal production cost, every manufacturer seeks for a low surface roughness, minimal tool wear, and least power consumption in turning process. Application of lubrication system in the metal cutting industry is one of the solutions used to cope with the demands. However, the high volume of cutting lubricant consumption during the cutting process has increased the machining cost. Recycle and reuse of cutting fluids not only reduced the effectiveness of the cutting fluids but also cause harm to human due to the growth of a micro-organism. Additionally, disposal of lubricant into river and sea pollutes the environment. In terms of the machining process, production of wet chip needs further separation process which increases the cost. Nanolubricants is a lubrication alternative to improve machining output, a cost saving and less harmful cutting lubricant to human and nature. The ability of nanolubricants to reduce friction at the cutting zone can improve the machining result. But, the agglomeration of nanoparticles that leads to sedimentation of nanoparticles after a period of time was suspected to reduces nanolubricants efficiency. Hence, the surfactant approach in stabilizing nanolubricants for a longer period of time appears to be a viable solution. However, the limited study on the performance of nanolubricants with surfactant has restricted the fundamental understanding on their effect on mechanics of machining process.

1.3 Objectives

The primary objective of this study is to elucidate the machining quality characteristics of the nanolubricants with surfactant coolant based. This can be achieved through a series of more detailed objectives as listed below:

a) To investigate the characteristic of aluminum oxide (Al_2O_3) nanolubricants with surfactant prior to machining tests.

b) To investigate the effects of Al_2O_3 nanolubricants with surfactant on surface roughness, tool wear and power consumption in turning of titanium alloy under minimum quantity lubricant (MQL) conditions.

c) To determine the optimum machining parameters under nanolubricants with surfactant by using Taguchi method combined with Grey Relational Analysis.

1.4 Scope and limitation

The scopes and limitations in this research are stated as below:

a) Nanolubricants made of Al_2O_3 as nanoparticles, solcut oil as base fluid and Tween 20, Tween 80 and SDBS (sodium dodecyl benzene sulfonate) as surfactant.

b) Stability of nanolubricants with surfactant in terms of manufacturing process.

c) Turning process with titanium alloy of Ti-6AL-4V type as the workpiece.

d) Cutting tools type is finishing type cemented titanium nitride (TiN) coated carbides.

e) Coolant approaches of dry, flood and MQL condition.

1.5 Significance/ Contribution of study

The significant of this study can be divided into two perspectives, which are theoretical and in industrial practice.

a) Knowledge contribution:

The output of this study will contribute in existing literature regarding the application of nanolubricants in machining domain. This finding could be further explored in solving issues related with heat transfer during machining process.

b) Industrial practice:

The proposed cutting fluid is capable of enhancing machining processes and output such as surface roughness and tool wear. Product quality will improve at the same time reduce machining cost. Usage of nanolubricants will reduce the consumption of cutting fluids consequently, less pollution will be caused.

1.6 Report outline

This report is divided into five chapters:

Chapter 1 represents the general introduction to this research study. This includes the problem statements, research objectives as well as the scopes and limitations. This chapter ended by description of the significance to study and the contributions of this research.

Chapter 2 explains some of the theories and research done by previous researcher related to the nanolubricants, surfactant, and advantages of minimum quantity lubrication (MQL), as well as machinability of titanium alloy. Finally, the Grey Relational Analysis and research gap ends this chapter.

Chapter 3 presents the research methodology, which include the methods and techniques expected to be used within this study. The explanations also comprise the selection of materials and cutting tool. All the machines used for data acquisitions are also presented throughout this chapter.

Chapter 4 discusses on the results obtained through this study. The discussion starts with the characteristics of nanolubricants with different type of surfactant and the amount used. This is then followed with experimental results, that are divided into two groups; comparison of surfactant type and comparison with normal cutting condition. The chapter continues with Taguchi experimental result followed with statistical analysis of variance (ANOVA). The chapter ends with the identification of best machining parameter combination promotes by the Grey Relational Analysis (GRA).

Chapter 5 concludes the significant findings that are obtained within this research scope. This chapter also describes the contributions of this study and recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the important topics related to this project, namely on the evolution of nanolubricants, state of the art of the minimum quantity lubricant (MQL), and machinability of titanium alloy. The reviews also cover the Taguchi method and Grey Relational Analysis which are used for planning the experimental investigations.

2.2 Evolution of nanolubricants

Nanolubricants assisted machining has appeared to be one of the competence solutions in improving machining performance as compared to that of traditional cutting fluids. Additional of nanoparticles inside the base fluids improves the fluids characteristics. Nanoparticles are endowed with good tribological characteristic. The size of particles, that is very small makes it easy to penetrate and slide over into small cutting region which, will creates a surface protective film on the friction surface by performing a rolling effect and filling valleys between surfaces that compensates for the loss of mass. Nanolubricants also have high heat transfer coefficient, thermal conductivity, flash and fire points and viscosity when compared to the base fluids. All these effects makes nanolubricants good in reducing friction, wear and heat during cutting process (Luo et al., 2014; M. Sayuti et al., 2014).

From economic viewpoint, nanolubricants for sure will cost more (based on the type of nanoparticles and the amount of concentration consume) as compared to ordinary cutting lubricant. But, the benefits provide by nanolubricants especially in improving certain output such as energy consumption and tool life will be a profitable investment for long term usage. In Rahmati et al. (2014) research, the authors had compared the price for 1L of nanolubricants which is roughly about 6.41 USD as compared to 6.25 USD for ordinary cutting lubricant. Although the price is a bit expensive than an ordinary cutting lubricant, nanolubricantion is unavoidable, especially in heavy duty machining where ordinary lubricant cannot withstand the high contact pressure and temperature.

Majority of the researchers who have carried out research on nanolubricants assisted machining, claimed that performance of machining increases with the use of nanolubricants. This includes increase of tool life, smoother surface finish, lower cutting force and lower cutting temperature. The mechanisms behind friction reduction have been suggested to be the rolling effect, ball bearing effect, protective film, mending effect, colloidal effect, and third body material transfer, as depicted Figure 2.1 (Rahmati et al., 2014; Sayuti et al., 2014).