Faculty of Manufacturing Engineering

THE INFLUENCE OF TOOL GEOMETRY TOWARDS CUTTING PERFORMANCE ON ALUMINIUM 7075

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DECLARATION

I declare that this thesis entitled "The Influence of Tool Geometry Towards Cutting Performance on Aluminium 7075" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : MUHAMMAD SYAFIK JUMALI

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality as a partial fulfillment of Master of Science in Manufacturing Engineering.

Signature :……………………………………………....

Supervisor's Name :……………………………………………....

Date :………………………………………………

ABSTRACT

Aerospace industries often use machining while manufacturing aerospace parts. Machining is done using general endmills that have helix angle of 30^o. These endmills give mixed machining results of surface roughness and tool wear depending on the tool manufacturer. This research aims to produce endmill with optimum geometry in terms of the helix angle, primary radial relief angle and secondary relief angle. The endmill is tested on Aluminium 7075 and data on surface roughness and tool wear is collected. Endmill with 10 mm diameter of Tungsten Carbide material is used in this research. Helix angle is varied between 30^o-60^o, primary radial relief angle varied between 5^o-9^o while secondary relief angle varied between 14^o-17^o. Helix angle, primary relief angle and secondary relief angle are the variable parameters. Design of Experiment (DOE) using Full Factorial method is used to generate the matrix of endmill design. 8 samples are prepared with 1 replication means 16 end mills are produced in total. An L-shaped part is machined where the surface roughness is measured both radial and axial by using cutting speed of 600 m/min. Tool wear is examined by studying flank wear. The desirable endmill will have a combination of minimal surface roughness and tool wear. The results of this research show that higher helix angle gives higher tool wear, higher axial surface roughness and higher radial surface roughness and vice versa. Higher primary radial relief angle gives higher tool wear, lower radial surface roughness and higher axial surface roughness and vice versa. Higher secondary radial relief angle gives lower tool wear, higher radial surface roughness and lower axial surface roughness and vice versa. The optimum endmill parameter for helix angle, primary relief angle and secondary relief angle is 30^o, 9^o and 14^o respectively. This research will be very valuable for industries involved with machining Aluminium 7075 namely aerospace industries as it will provide the optimum endmill angles in order to machine Aluminium 7075.

ABSTRAK

Industri aero angkasa menggunakan pemesinan secara meluas dalam penghasilan komponen aero angkasa. Pemesinan dilakukan menggunakan mata alat pengisar umum yang mempunyai sudut heliks 30^o. Mata alat ini menghasilkan keputusan pemesinan melibatkan kekasaran permukaan dan kehausan mata alat yang bercampur bergantung kepada pengilang mata alat tersebut. Kajian ini bertujuan untuk menghasilkan mata alat pengisar yang mempunyai keadaan geometri yang optimum dari segi sudut heliks, sudut kelegaan jejarian primer dan sudut kelegaan sekunder. Mata alat pengisar ini diuji ke atas Aluminium 7075 seterusnya data berkenaan kekasaran permukaan dan juga kehausan mata alat dikumpulkan. Pengisar dengan diameter 10 mm dihasilkan menggunakan material Tungsten Karbida telah digunakan dalam kajian ini. Sudut heliks adalah di antara 30^o-60^o, sudut kelegaan jejarian primer antara 5^o-9^o dan sudut kelegaan sekunder antara 14^o-17^o. Design of Experiment (DOE) telah digunakan untuk menghasilkan sampel pengisar. 8 sampel dihasilkan dengan 1 replikasi menjadikan jumlah sampel sebanyak 16 sampel kesemuanya. Komponen berbentuk L dimesin di mana kekasaran permukaan jejarian dan juga paksian diukur setelah pemesinan. Kehausan mata alat diperiksa dari sudut kehausan rusuk. Pengisar yang diingini akan mempunyai kombinasi kekasaran permukaan dan kehausan mata alat yang minimal. Keputusan kajian ini menunjukkan semakin tinggi sudut heliks maka semakin tinggi kehausan mata alat, kekasaran permukaan paksian dan juga jejarian serta sebaliknya. Semakin tinggi sudut kelegaan jejarian primer, semakin tinggi kehausan mata alat, semakin rendah kekasaran permukaan jejarian, semakin tinggi kekasaran permukaan paksian serta sebaliknya. Semakin tinggi sudut kelegaan sekunder, semakin rendah kehausan mata alat, semakin tinggi kekasaran permukaan jejarian, semakin rendah kekasaran permukaan paksian dan begitulah sebaliknya. Parameter optimum mata alat bagi sudut heliks, sudut kelegaan jejarian primer dan sudut kelegaan sekunder adalah 30^o, 9^o and 14$^{o.}$ Kajian ini sangat berguna kepada industri yang terlibat dalam pemesinan Aluminium 7075 seperti industri aero angkasa kerana ia memberikan sudut mata alat optimum yang boleh digunakan untuk pemesinan Aluminium 7075.

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LIST OF ABBREVIATIONS

CAD – Computer Aided Design

CAM – Computer Aided Manufacturing

CATIA – Computer Aided Three-dimensional Interactive Application

CBN – Cubic Boron Nitride

CNC – Computer Numerical Control

DOE – Design of Experiment

FEPA – Federation Europeenne des Fabricants de Produits Abrasifs (European Federation of the Manufacturers of Abrasive Products)

GUI – Graphical User Interface

HSS – High-Speed Steel

NC – Numerical Control

RPM – Revolutions per Minute

TiC – Titanium Carbide

TiCN – Titanium Carbonitride

TiN – Titanium Nitride

WC – Tungsten Carbide

CHAPTER 1

INTRODUCTION

1.1 Background

Machining is the most common material removal process being practiced in the metal fabrication industry such as in the aerospace and automotive industries. This is due to the flexible nature of machining in that it can be used to produce almost any design features of metal components. The capability of machining is hugely improved through the introduction of advanced technologies such as Computer Numerical Control (CNC) and Computer-Aided Manufacturing (CAM). Computer Numerical Control (CNC) machining is the process of using a computer to control a machine tool. Computer-Aided Manufacturing (CAM) is the use of a computer to aid manufacturing processes.

In conventional machining, machine tool motions are controlled manually by the machinist. These motions include table motions (X, Y and Z) and also spindle head motions (during drilling process). In order to get good machining results; in terms of dimensional accuracy and surface finish, the machinist must be highly skilled and having years of experience will contribute significantly to the outcome of the finished product. Highly skilful machinist will, therefore, have a higher productivity as compared to a new and less skilful machinist.

Computer Numerical Control (CNC) machining, on the other hand, is using a computer to control the motions of the machine tool. The movements of the machine tool are controlled by using numbers. Computer programs use programming languages called G-codes and M-codes to program the cutting motions namely, positioning, spindle speed, feed rate and also the non-cutting motions namely coolant on/off, spindle on/off, end of the program etc. Machine tools manufacturers often have their own programming languages to simplify the process of creating CNC programs. The programming languages are also known as the controllers. Commonly used controllers in the market are Fanuc, Mitsubishi, Heidenhain, Siemens, Mazatrol etc. It is very common in the machine tool industry that similar brand and model of a particular manufacturer may have a different controller fitted on the machine tool. This is purposely done by manufacturers to attract buyers that are currently using a different machine tool brand to buy their machine since machining companies tend to try to avoid retraining of their machinist if they were to buy a different controller. Changing to a new controller also means that they will have to change the CNC programs of current products that are using the old controllers to the new controller if they were to produce the old product with the new machine, which will be time and cost consuming.

Computer-Aided Manufacturing (CAM) is the use of software to control machine tools in a manufacturing industry in order to manufacture workpieces. CAM technology is very essential as it improves manufacturing by reducing cost, increasing productivity, simplifying complexity and adding versatility. There is a lot of CAM software available in the market. Names like Delcam, CATIA, Solidcam, Mastercam, Surfcam, Esprit and CAMWorks are a few examples of CAM software. Each CAM software has its own strengths and weaknesses. Some software focuses into a particular industry, for example aerospace, automotive, mould making, medical and even arts. Delcam is a very well-known software that is very famous for its ability in mould making industry. Finished moulds are said to have no or very little need for polishing as is the norm.

CAM software focuses on specific industries because each industry has its own unique set of challenges to overcome. Another example, aerospace industry focuses more on the machining of aluminium and titanium as they are lightweight materials that are commonly in use in aircrafts. These two materials are almost at both extremes of material properties in terms of machinability. Aluminium alloys are lightweight and easier to machine even though it has the tendency to melt during high speed machining if proper cooling is not applied (www.kennametal.com). As compared to titanium however, which are lightweight but has very low machinability and hard to machine. Part of the reason is the low thermal conductivity of titanium does not allow the heat generated during machining to dissipate from the tool edge. This causes high tool tip temperatures and excessive tool deformation and wear. Titanium is also very popular in medical industry as they are used in hip and knee replacement surgeries as pins, bone plates etc. This is due to the properties of titanium that are strong, lightweight, corrosion resistant non-ferromagnetic and long lasting which are very useful and almost similar to human bones.

The world today is moving at a very fast rate. Parts have to be manufactured in half the time needed previously, products needed to be introduced to the market faster, improvements on current products needed to be done immediately and so on. This leads to the introduction of High Speed Machining. There are a few definitions of High Speed Machining. One of them is; high-speed machining is defined as machining using average spindle speeds greater than 10,000 rpm, which can generate surface speeds in excess of 6 m/s (Campbell et.al, 2006). This is a rather loose definition as the end target is high material removal rate; sometimes slower spindle speed but higher feed rate can also lead to high material removal rate. The technique behind High Speed Machining is mostly by using different CAM toolpath strategies that manipulates or using constant tool engagement angle while machining. By using constant tool engagement angle, spindle load and chip ejection is kept constant thereby maintaining tool life as well as getting a higher production rate. Conventional machining strategies often have varied feed rates during cutting. The variation is applied when machining corners whereby the feed rate is lowered so as to protect from high spindle load. Current cutting strategies eliminate feed rate variation by changing the approach to corners. Rather than going in a straight line at a reduced feed rate, feed rate is maintained but tool path is changed from a straight line to trochoidal path. The advantage is machining can be done at a faster rate as the feed rate is maintained thus deeper cut can be used therefore increasing the material removal rate.

In aerospace industry where volume is low and flexibility is high, machining is one the most profitable and viable methods of production. Machining method using CNC machines is often used to produce aerospace parts. Variable parameters in machining are spindle speed, feed rate and depth of cut. These three parameters partly determine whether any parts that are produced have good surface finish while improving cutting tool performance and having longer tool life during machining. However, in modern CAM software, higher cutting speed is obtained by manipulating different cutting strategies in order to fully utilize the capabilities of CNC machines.

Machining is a process that directly involves cutting tools as the tool to remove material. There are various types of cutting tools available in the market that serves different purposes in machining. A twist drill, for example, is used to drill holes in materials according to the desired diameter. A reamer is used to minutely enlarge a hole that was previously drilled using a twist drill to get a better surface finish and tolerance on the hole. An end mill is a very commonly used cutting tool in machining; used to remove material according to the desired design. The most common variation of end mill comes in the form of its diameter, number of flutes as well as the material, such as High Speed Steel, Carbide, Ceramic, types of coating applied and so on. These variations will determine the workpiece material to be cut, the process of cutting (roughing, semi finishing or finishing), cutting speed etc.

Cutting tool and machining go hand in hand in that one cannot work without the other. The use of correct cutting tools and cutting parameters will ensure that the machining process produces the desired results. A cutting tool such as an end mill has its own geometry that influences its performance during machining. This is because the geometry determines the material removal rate, chip flow and coolant flow. These, in turn, affect the end mill tool life itself and also the part produced in terms of surface finish and meeting the specified tolerance. In order to produce optimum machining results, end mill geometry, along with optimum spindle speed and feed rate are essential parameters that need to be controlled.

1.2 Problem Statement

Where machining is concerned, it will always involve cutting tool, cutting speed, feed rate, depth of cut, cutting force, tool wear, surface finish and dimensional accuracy. Often the main problem in machining is tool wear. The selected tool might be able to cut the desired material, but if the tool wear rate is too high, it is undesirable to the economics of machining. It is, therefore, essential that the tool used will be able to cut the material at high speed with low tool wear. Finding the right balance between cutting speed and tool wear is often the issues to be addressed in a machining environment.

In order to investigate the relationship between cutting speed with surface finish and tool wear, a combination of varied primary and secondary clearance angles and also the flute helix angle of end mill will be used to determine the optimum tool geometry to cut Aluminium 7075. Aluminium 7075 is commonly used for aircraft structures because it has high strength and also the best machinability among Aluminium Alloys (Dursun and Soutis, 2014). Many researchers studied the effects of helix angle to vibrations. Omar et al. (2007) found that cutting forces decrease as helix angle increases. Zatarain et al. (2006) found that helix angle reduces the importance of higher order harmonics vibrations. The effect of helix angle on surface roughness is studied by Buj-Corral et. al (2011) who pointed out that for helix angles other than zero, the same roughness pattern appears on the workpiece's surface along each helix pitch regardless of helix angle. However, the research was done by cutting steel. Vobrouček (2015) suggested for changing surface quality, friction and toughness of mill, we must change the clearance angle on the tool; the research was done by cutting Akrylonitrilbutadienstyren (ABS) plastic. As of now, no research has been done to study the effect of tool geometry on Aluminium 7075.

1.3 Research Objectives

The objectives of this study are as follow:

a) To identify the effects of different primary and secondary radial relief angle of end mill on tool wear of Uncoated Tungsten Carbide.
b) To identify the effects of helix angle on tool wear of Uncoated Tungsten Carbide.
c) To investigate the effects of varied primary and secondary radial relief angle of end mill on the surface finish of machined Aluminium 7075.
d) Optimization of tool geometry.

1.4 Research Scope

This research will focus on tool wear of uncoated Tungsten Carbide end mill of diameter 10 mm in which the tool geometry is varied while cutting speed, v_c, feed rate, *f*, and depth of cut, a_p, are kept constant, and the surface finish of Aluminium 7075 after machining. High Speed Machining is used to produce L-shaped part where the part was later examined for surface finish and the end mill used to cut the part will be checked for tool wear. This part is chosen because the bottom and side is the cut area that relates to the primary and secondary relief angle.

This research does not cover different types of end mill materials, or different diameters of end mills as well as not taking into consideration other materials, only focusing on Aluminium 7075. Cutting is done using flood coolant.

1.5 Research Significance

The result of this research can be applied by aerospace industry to increase productivity and because companies can utilize the recommended angles from this research to produce custom made end mills with longer tool life as well as producing excellent surface finish during machining as compared to end mills in the market which are often sold with standard geometries. Readily available end mills in the market only provide variation in terms of the helix angle and these end mills are 30^o, 45^o and 60^o. If end mills are able to cut with excellent surface finish, this will reduce the need to do the additional secondary process of finishing such as polishing which is often the case in mold making industry. This will subsequently reduce the cycle time to manufacture the part. Toolmakers can also use the findings of this research to better cater the needs of their customers in the aerospace industries.