MACHINABILITY STUDY OF COATED AND UNCOATED CARBIDE TOOLS IN DRILLING INCONEL 718

RIVAL

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Specially dedicated to *my parents and all family members*

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ABSTRACT

Advanced materials such as aero-engine alloys, structural ceramics and hardened steels pose serious challenges for cutting tools material during machining. Nickel-base super alloys are generally known to be one of the most difficult materials to machine. Machining productivity can be significantly improved by employing the right combination of cutting tools, cutting conditions and machine tool without compromising the integrity and tolerance of the machined components. The objectives of this study are to evaluate the machining characteristics of new drill geometry and to established mathematical model of the responses when drilling Inconel 718 using various cutting conditions. Commercially available Inconel 718 was drilled using carbide cutting tool with various point angles at various cutting speed between 4.59 to 21.41 m/min and feed between 0.03 to 0.12 mm/rev in the wet condition and a constant depth of cut. The drills employed in this study were uncoated carbide, TiAlN coated carbide and AlTiN coated carbide with designated ISO grade K20/K30. The performance of the cutting tools in terms of tool life (T), surface roughness (Ra), cutting forces (Fz) and diameter error (DE) was described using factorial design and response surface methodology (RSM). Mathematical models of the drilling responses were developed using the proposed method. Results showed that the developed models were statistically valid and sound based on the experimental results within the acceptable range. The optimum cutting conditions were developed for all the responses with acceptable desirability. Dimensional accuracy and surface layer alteration of the drilled hole when using all type of cutting tools were compared traditionally between three different types of tool. Results showed that the accuracy varied for all chosen machining conditions and tool types but still within acceptable tolerance. Top surface layer and subsurface are significantly affected with ununiform layer and the presence of white layer. Highest microhardness at subsurface layer occured when using AlTiN coated carbide tool.

ABSTRAK

Bahan termaju seperti aloi angkasa, seramik struktur dan keluli yang dikeraskan memberi cabaran yang serius pada bahan matalat semasa proses pemotongan. Aloi berasas nikel merupakan salah satu bahan yang sangat sukar untuk dimesin. Produktiviti pemesinan dapat ditingkatkan dengan menggunakan kombinasi sesuai pada matalat, keadaan pemotongan dan mesin yang digunakan dengan memperhatikan integriti dan had terima produk yang dimesin. Tujuan penyelidikan ini adalah untuk menilai sifat dari pemesinan matalat yang berbeza geometri dan pembangunan model matematik terhadap respon semasa menggerudi Inconel 718 dengan pelbagai keadaan pemotongan. Penggerudian menggunakan matalat karbida pelbagai sudut geometri pada pelbagai halaju pemotongan di antara 4.59 hingga 21.41 m/min, kadar suapan di antara 0.03 hingga 0.12 mm/pusingan dalam keadaan basah dengan kedalaman pemotongan tetap. Matalat gerudi yang digunakan adalah karbida tak bersalut, karbida bersalut TiAlN dan AlTiN bergred ISO K20/K30. Prestasi matalat seperti hayat matalat (T), kekasaran permukaaan (Ra), daya pemotongan (Fz), dan ketepatan diameter (DE) dinyatakan menggunakan kaedah reka bentuk pemfaktoran dan permukaan respon (RSM). Model matematik bagi respon proses penggerudian dibangun menggunakan kaedah di atas. Keputusan menunjukkan bahwa model yang dibangun adalah sah dan kukuh berdasar hasil keputusan yang diperolehi di dalam lingkungan yang dikaji. Keadaan pemesinan yang optimum juga dibangunkan untuk semua respon pemesinan dengan keperluan yang dapat diterima. Ketepatan dimensi dan lapisan permukaan lubang yang digerudi ketika menggunakan berbagai matalat dibandingkan di antara ketiga-tiga matalat. Keputusan menunjukkan adanya variasi ketepatan pada semua keadaan pemotongan dan matalat, namun ianya masih dalam ketepatan had terima. Lapisan permukaan dan bahagiannya dipengaruhi lapisan tak seragam di lapisan putih. Kekerasan yang tinggi pada lapisan permukaan berlaku ketika menggunakan karbida bersalut AlTiN.

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LIST OF ABBREVIATIONS AND SYMBOLS

A	-	Factor of cutting speed
B	-	Factor of feed
C	-	Factor of point angle
ANOVA	-	Analysis of variance
BUE	-	Built up edge
CCD	-	Central composite design
CMM	-	Coordinate measuring machine
DE	-	Diameter error (mm)
D_A	-	Average hole diameter
D_T	-	Tool diameter
Fz	-	Cutting force/thrust force (N)
f	-	feed (mm/rev)
HRC	-	Hardness Rockwell unit
RSM	-	Response surface methodology
Ra	-	Surface roughness (µm)
SEM	-	Scanning electron microscopy
T	-	Tool life (minute)
$x_1, x_2, x_3,..,x_k$	-	Input variables

α - Point angle (degree)

Vc - Cutting speed (m/min)

y - Response

ε - Error

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CHAPTER 1

INTRODUCTION

1.1 Overview

Advanced materials such as superalloys aero-engine alloys, structural ceramic and hardened steels posses serious challenges to cutting tools material during machining. Superalloys are heat resistant alloys of nickel, nickel-iron, or cobalt that exhibit a combination of mechanical strength and resistance to surface degradation generally not similar to the other metallic compounds. The primary uses of these alloys are in; (a) gas turbines for aircraft, such as discs, combustion chambers, bolts, castings, system in shaft exhaust, blades , vanes; (b) steam turbines in power plants, likes bolts, blades, heaters in stack gas; (c) reciprocated engines, likes in turbocharger, valves at the exhaust, hot plugs, etc.; (d) metal processing, likes for hot work tool and dies, dies for casting; (e) medical equipments, such as parts in dentistry, prosthetic devices; (f) space shuttles; (g) heat treatment equipment; (h) nuclear power plant; (i) petrochemical and chemical industries; (j) equipment for pollution control; and (k) coal gasification and liquefaction system (Choudury and El Baradie, 1998). Content of nickel is about 50% in nickel base alloys, where else in nickel-iron base alloy, nickel is found to be the main solute component.

Among the nickel base superalloys, Inconel is generally known to be one of the most difficult materials to be machined because of its high hardness, high strength at high temperature, affinity to react with tool materials, and low thermal diffusivity. Nickel base superalloys have some characteristics that are responsible for its poor machinability. They have an austenitic matrix, and like stainless steels, they work hardened rapidly during machining. These alloys also have the tendency to weld with the tool material due to the high temperature generated during machining. The tendency to form BUE (built up edge) during machining and the presence of hard abrasive carbides in their microstructure also deters machinability. Machinability is the term used to describe how easily a material can be cut to a desired shape with respect to the tooling and machining processes involved. Machining productivity can be significantly improved by employing the right combination of cutting tools, cutting conditions and machine tool without compromising the integrity and tolerance of the machined components. This is particularly essential for the economic machining of difficult to machine materials such as Inconel 718.

1.2 Background of Research

Most of research findings on the machinability of Inconel have dealt with the turning operation and, to a certain extent, milling operation. The machinability of Inconel in drilling operation has not been widely reported. This may come as surprise as hole drilling is among the most common and demanding process in machining. New machining conditions on drilling of Inconel could be further exploited. Further research on drilling mechanism and its effect on this kind of material will ensure better machining efficiency.

This study is undertaken to investigate the performance of new drill geometry of coated and uncoated carbide when drilling Inconel 718 under various cutting conditions. Design of experiment (DOE) approach is used to develop mathematical models for the selected machining responses when drilling of Inconel 718.

The continuing demand for improved productivity through the use of properly selected drilling tool and drilling conditions for a given application has generated interest in understanding the drilling performance on the selected material. It is expected that the findings from this research would enhance new knowledge and provide a better understanding of the machining characteristics when drilling of

Inconel 718. In addition, it would provide significant benefits to the machining industries in particular aerospace and petrochemical industries.

1.3 Problem Statement

Does the performance of different drill geometry and coating of carbide tool when drilling Inconel 718 deliver better results in term of surface integrity, cutting forces, tool life and dimensional accuracy.

1.4 Objectives

The objectives of the study comprising the following:

i. To determine the optimum machining conditions when drilling Inconel 718 using uncoated and coated carbide tools of different tool geometry
ii. To develop mathematical models for tool life, surface roughness and cutting force of uncoated and coated carbide tools when drilling Inconel 718
iii. To evaluate the effect of the cutting conditions on tool life, tool wear, cutting force when drilling Inconel 718
iv. To study the surface integrity and microhardness of the drilled hole by mean of quality from different type of tools and geometry
v. To investigate the dimensional accuracy in terms of diameter and roundness of the drilled hole when drilling Inconel 718 by using different type of tools and geometry

1.5 Scope of Study

The scope of this research is focused on drilling Inconel 718 using three types of cutting tools, which include uncoated and two coated carbide tools (TiAlN and AlTiN). Experimental studies were conducted under various independent variables which include cutting speed, feed rate, geometry and coatings material. In this study, the cutting speed applied in the range of 4.59 to 21.41 m/min and feed rate between 0.03 to 0.012 mm/rev. The geometry of the tool was specially manufactured with different point angle in the range 116.5 to 133.4 degree. The workpiece was mounted above dynometer to record the produced force when drilling with wet condition. At the end of the study the performance of each cutting tools was evaluated by means of factorial design and response surface methodology (RSM), then mathematical models (empirical equations) for tool life, surface roughness, cutting force and diameter error were developed. Subsequently, the optimum cutting conditions for carbide tools in drilling Inconel 718 were established. The surface characteristics and dimensional accuracy were investigated based on the quality criteria.

1.6 Significance of Study

The enormous cost involved in the machining of nickel alloys and other aerospace materials has prompted continuous research and development of suitable cutting tool materials and geometries, as well as cutting techniques that ensure greater material removal rate with minimum surface and subsurface damages to the machined component. Although research on drilling had been conducted expensively, investigations on the drilling of nickel base superalloys are still limited especially in relation to optimization of cutting conditions on the machining responses. In this study the machining parameters such as cutting speed, feed rate was selected within wide range of value to identify several behavior of independent variables. The geometry of the tools was set especially the point angle which cover the geometry that commercially available. The mathematical models that are developed can assist the aerospace industries to determine suitable conditions in drilling Inconel 718 within the range of this study for a specific target. Eventually, this will help to reduce the cost and time to the aerospace machining industries in the future. Dimensional accuracy in term of hole diameter and roundness that produced by drilling process were investigate especially in relation to the tool types and geometry. Surface and subsurface of the drilled holes are thoroughly investigated in terms of surface layer, microcracks and hardness.

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