EFFECTS OF CUTTING STRATEGY IN THE CONTOUR MILLING OF OPEN POCKET AISI H13 WITH A LOW RATIO THIN-WALLED FEATURE

BY

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ABSTRACT

In the pocket machining of hard material with a thin-walled structure, the selection of cutting strategy and conditions significantly influences the process, machined part, and tool condition outputs. Variations in cutting engagement variables, including cutting speed, feed rate, and depth of cut, could either significantly improve or deteriorate the cutting time components, machined part quality, and tool conditions to certain levels. This research combined the roughing and finishing operations in the pocket milling of hardened AISI H13 tool steel. Two consecutive cutting processes, with different contour tool paths, were integrated into a single operation (run) made for two distinct features of open pocket lateral wall and low-ratio thin-walled feature.

The organisation of the research was made into two consecutive parts. The first part was carried out entirely through the conduct of virtual machining for the development of tool path and the investigation of simulated machining time, while the second part was focused on the actual machining to collect experimental data for the characterisation of the process, workpiece and tool wear. Supersaturated response surface methods: Definitive screening design (DSD) was used as the experimental design where eleven independent variables were employed for the virtual machining, and six independent variables were employed for the actual cutting processes.

The simulated feeding time and rapid time results indicated that the axial and radial depth of cuts, the incremental distance of feeding and rapid planes, as well as the fixed components and rapid traverse speed overrides were among the variables that contributed to the tool path length; hence, increasing the machining time. In terms of actual machining, the significant variables for the open pocket wall machining were (1) cutting speed v_c(OP), (2) feed rate v_f(OP), (3) and depth-of-cut for finishing operation DOC_f, and for the thin-walled feature machining were (1) the depth-of-cut for roughing operation DOC_r, (2) cutting speed v_c(TW), (3) and feed rate v_f(TW). The observations on cutting temperature suggested that the two cutting processes of open pocket wall and thin-walled feature differed due to the different radial depth of cut. The maximum observable cutting temperature for the machining of the open pocket wall was 278.1 ˚C, while the thin-walled feature was 107.9 ˚C. The surface roughness was ranged from 0.09 to 0.27 μm for the pocket floor, 0.35 to 2.03 μm for the lateral pocket wall, and 0.15 to 1.58 μm for the thin-walled feature. Furthermore, the observations on mechanical surface alterations showed the presence of built-up edge, burr, and feed marks in almost all experimental runs.

The findings of this research were expected to be useful for other researchers and industrial practitioners by providing valuable multiple data that could act as a point of reference in carrying out similar processes. In this case, the research parameters can be further adapted for the production of parts with certain desired outputs, particularly in terms of machined part tolerances, allowances, and surface roughness. Furthermore, the data from tool damage observations can also be adopted to further develop the tool life estimation from the application of a similar tool class.

خلاصة البحث

عند تشكيل التجويف للمواد الصلبة بهيكل رقيق الجدار، يؤثر اختيار استراتيجية القطع وظروفها بشكل كبير على العملية والجزء المشكّل ومخرجات حالة الأداة. يمكن أن تؤدي الاختلافات في متغيرات المشاغَلة، بما في ذلك سرعة القطع ومعدّل التغذية وعمق القطع، إلى تحسين أو تدهور عناصر زمن القطع وجودة الأجزاء المشّكلَة وحالة الأداة إلى حدّ معين. دمج هذا البحث بين عمليات التخشين والصّقل في التجويف الآلي لأداة الفولاذ AISI H13 الصلبة. تم دمج عمليتي قطع متتاليتين، مع مسارات محيطية مختلفة للأداة، في عملية واحدة (شُغل) صُنعت لميزتين بارزتين للجدار الجانبي للتجويف المفتوح وخاصية الجدران الرقيقة منخفضة النسبة.

تم تنظيم البحث في جزأين متتاليين. تمّ تنفيذ الجزء الأول بالكامل من خلال إجراء معالجة افتراضية لتطوير مسار الأداة والتحقيق في زمن المعالجة المحاكاة، بينما ركّز الجزء الثاني على المعالجة الفعلية لجمع البيانات التجريبية لتوصيف العملية وقطعة التشغيل وتلف أداة القطع. طرق سطح الاستجابة المفرطة التشبع: تم استخدام تصميم الفحص المحدَّد (DSD) كتصميم تجريبي حيث تم توظيف أحد عشر متغيرًا مستقلاً للمعالجة الافتراضية وستّ متغيرات مستقلة لعمليات القطع الفعلية.

أشارت نتائج وقت التغذية المحاكي والوقت السريع إلى أن العمق المحوري والشعاعي للقطع، والمسافة المتزايدة للتغذية والمستويات السريعة، بالإضافة إلى العناصر الثابتة وقيمة تجاوز سرعة التمرير كانت من بين المتغيرات التي ساهمت في طول مسار الأداة ؛ وبالتالي، زيادة زمن المعالجة. فيما يتعلق بالآلات الفعلية، كانت المتغيرات المهمة لتشكيل جدار التجويف المفتوح هي (1) سرعة القطع $v_c(OP)$، (2) معدّل التغذية $v_f(OP)$، (3) وعمق القطع DOC_r لإنهاء عملية الصّقل، بينما لميزة الجدران الرقيقة كانت المتغيرات (1) عمق القطع لعملية التخشين DOC_r ، (2) سرعة القطع v_c(TW)، (3) ومعدل التغذية v_f(TW). اقترحت الملاحظات على درجة حرارة القطع أن عمليتي القطع لجدار التجويف المفتوح وخاصية الجدران الرقيقة اختلفتا بسبب اختلاف العمق الشعاعي للقطع. كانت أقصى درجة حرارة قطع يمكن ملاحظتها لتشكيل جدار التجويف المفتوح 278.1 درجة مئوية، بينما كانت لميزة الجدران الرقيقة 107.9 درجة مئوية. تراوحت خشونة السطح من 0.09 إلى 0.27 ميكرومتر لأرضية التجويف، ومن 0.35 إلى 2.03 ميكرومتر لجدار التجويف الجانبي، ومن 0.15 إلى 1.58 ميكرومتر لميزة الجدران الرقيقة. علاوة على ذلك، أظهرت الملاحظات على التعديلات الميكانيكية السطحية وجود حافة مدمجة وعلامات نتوء وتغذية في جميع الأشواط التجريبية تقريبًا.

كان من المتوقع أن تكون نتائج هذا البحث مفيدة للباحثين والممارسين الصناعيين من خلال توفير بيانات متعددة قيّمة يمكن أن تكون بمثابة نقطة مرجعية في تنفيذ عمليات مماثِلة. وفي هذه الحالة، يمكن ملاءمة متغيّرات البحث لإنتاج أجزاء ذات نواتج مرغوبة، لاسيما فيما يتعلق بتفاوتات الأجزاء المشكّلة والبدلات وخشونة السطح. علاوة على ذلك، يمكن أيضًا اعتماد البيانات من ملاحظات تلف أداة القطع لمواصلة تطوير تقدير عمر الأداة من تطبيق فئة أداة مماثلة.

APPROVAL PAGE

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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"…And when ye are told to rise up, rise up. Allah will raise up, to (suitable) ranks (and degrees), those of you who believe and who have been granted (mystic) Knowledge. And Allah is well-acquainted with all ye do" [Quran, 58: 11]

For my late father and sister, from whom I learned kindness, and to whom I attributed whatever good things that ever happened, and will come to pass, through my actions.

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LIST OF ABBREVIATIONS

AISI	American Iron and Steel Institute
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
ANSI	American National Standards Institute
BUE	Built-Up Edge
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CBN	Cubic Boron Nitride
CFRP	Carbon-Fibre Reinforced Plastic
CNC	Computer Numerical Control
DFFITS	Difference in Fits
DIN	*Deutsches Institut für Normung* eV (German Institute for Standardization)
DOE	Design of Experiment
DSD	Definitive Screening Design
FEM	Finite Element Method
HRC	Rockwell C Hardness
HSS	High Speed Steel
HV	Vickers Pyramid Number
ISO	International Organization for Standardization
MRR	Material Removal Rate
NC	Numerical Control
PCBN	Polycrystalline Cubic Boron Nitride
PCD	Polycrystalline Diamond
PVD	Physical Vapor Deposition
RSM	Response Surface Methodology
VM	Virtual Machining
VMC	Vertical Machining Centre

LIST OF SYMBOLS

ADOC	Axial depth of cut (mm)
ADOC-r	Axial depth of cut for roughing processes (mm)
ADOC-fc	Number of finishing step for axial depth of cut (step)
ADOC-fs	Axial depth of cut for surface finish (mm)
D_c	Tool cutting diameter (mm)
FPD	Cutting feed-plane incremental distance (mm)
l_F	Feeding length during one machining process
l_R	Rapid length during one machining process
R_a	Mean surface roughness (μm)
RDOC	Radial depth of cut (mm)
RDOC-fc	Number of finishing step in radial cutting (mm)
RDOC-fs	Radial depth of cut for surface finish (mm)
RPD	Retract-plane incremental distance
t_F	Feeding time (min)
t_R	Rapid (motion) time (second)
T_c	Machining cutting temperature (°C)
v_c	Cutting speed (m/min)
v_{cf}	Cutting speed for surface finish (m/min)
v_f	Feed rate (mm/min)
v_{ff}	Feed rate for surface finish (mm/min)
W_p	Dimension deviations for overall pocket width (mm)
W_{pw}	Dimension deviations of thin walled relative position (mm)
W_w	Dimension deviations of thin-walled feature's width (mm)