DISSERTATION

PERFORMANCE EVALUATION OF GREEN MACHINING ON THIN-WALLED TI6AL4V USING RESPONSE SURFACE METHODOLOGY AND ARTIFICIAL NEURAL NETWORKS

MUHAMMAD YANIS
NIM. 03043621520005

ENGINEERING STUDY PROGRAM DOCTORAL PROGRAM
FACULTY OF ENGINEERING
SRIWIJAYA UNIVERSITY

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By

MUHAMMAD YANIS
NIM. 03043621520005

Palembang, November 2019

Supervisor

Dipl. -Ing. Ir. Amrifan Saladin Mohruni, Ph.D
NIP. 19640911 199903 1002

Co-Supervisor-1

Prof. Dr. Safian Sharif
I/C No. 610621-04-5235

Co-Supervisor-2

Irsyadi Yani, ST., M.Eng., Ph.D
NIP. 19711225 199702 1001

Approved by,
Faculty of Engineering
Dean,

Prof. Ir. Subriyer Nasir, M. S., Ph.D
NIP. 19600909 198703 1 004

PAGE OF APPROVAL

Dissertation entitled "Performance Evaluation of Green Machining on Thin-Walled Ti6Al4V using Response Surface Methodology and Artificial Neural Networks" has been defended in front of the Doctoral Promotion Examination Team, Doctor of Engineering - Faculty of Engineering, Sriwijaya University on November 20, 2019.

Palembang, November 2019

Chairman of the Examiner Team:

1. Prof. Ir. Subriyer Nasir, M. S., Ph.D
   NIP. 19600909 198703 1 004 ( )

Examiner Team Members::

1. Prof. Dr. Ir. Nukman, MT
   NIP. 19590321 198703 1 001 ( )

2. Gusry Akhyar Ibrahim, ST., MT., Ph.D
   NIP. 19710817 199802 1 003 ( )

3. Agung Mataram, ST., MT., Ph.D
   NIP. 19790927 200312 1 004 ( )

Faculty of Engineering: Dean,	Coordinator of Study Program,
Prof. Ir. Subriyer Nasir, M. S., Ph.D NIP. 19600909 198703 1 004	Prof. Dr. Ir. Nukman, M. T NIP. 19590321 198703 1 001

KEMENTERIAN RISET, TEKNOLOGI, DAN PENDIDIKAN TINGGI
UNIVERSITAS SRIWIJAYA
FAKULTAS TEKNIK
Jalan Palembang-Prabumulih, KM 32 Inderalaya Kabupaten Ogan Ilir - 30662
Telepon (071 1) 580739, Faksimile (0711) 580741
Pos El ftunsri@unsri.ac.id

SURAT PERNYATAAN BEBAS PLAGIARISME

Yang bertanda tangan di bawah ini:

Nama	:	Muhammad Yanis
NIM	:	03043621520005
Tempat/Tanggal Lahir	:	Plaju / 28 Februari 1970
Jurusan Program Studi	:	Program Studi Ilmu Teknik Program Doktor
Fakultas	:	Teknik
Alamat Rumah	:	Jl. S. Mansyur Komplek Mutiara Siguntang No. 9 RT 02/01 Kelurahan Bukit Lama Kecamatan Ilir Barat I Palembang-30139
Nomor Telp/HP/E-Mail	:	08127872746 / yanis@unsri.ac.id

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Dibuat di : Palembang
Pada tanggal: 29 November 2019
Yang membuat pernyataan,

Muhammad Yanis
NIM. 03043621520005

SUMMARY

PERFORMANCE EVALUATION OF GREEN MACHINING ON THIN-WALLED TI6AL4V USING RESPONSE SURFACE METHODOLOGY AND ARTIFICIAL NEURAL NETWORKS

Scientific Paper in the form of Dissertation, November 2019

Muhammad Yanis; Supervisor Amrifan Saladin Mohruni
Co-Supervisor Safian Sharif and Irsyadi Yani

Performance Evaluation of Green Machining on Thin-Walled Ti6Al4V using Response Surface Methodology and Artificial Neural Networks.

xxvii + 205 Pages, 39 Tables, 58 Figures, 10 Appendixes

Milling of thin-walled components is very substantial in the modern aerospace industry. Aerospace component requires best engineering metals such Ti6Al4V alloy. This alloy even though have many superior advantages, but classified as difficult-to machine material. Poor machinability of Ti6Al4V thin-walled is a challenge. This study is necessary, also according to its complicated structure of thin-walled and complicated nature of Ti6Al4V under the influence of fluctuating cutting force. The fluctuation resulted vibration, therefore making it hard to support the expected surface finish.

In the interest of expected surface quality, this milling is also wiser obtained by green machining with the use of vegetable oil as non-toxic and ecofriendly cutting fluid. Neat coconut oil was chosen as a good local source. Thereafter, in an effort to minimize the price of coconut oil and the high cost of milling Ti6Al4V then machining operation achieved by the utilization of minimum quantity lubrication (MQL) technique.

The aim of this study was to evaluate the machining performance of Ti6Al4V on dependent variables (surface roughness R_a and cutting speed F_c). RSM and ANN were developed to determine modeling predictions and optimization. Variations in the value of independent variables (cutting speed V_c, feed rate f_z, radial a_r and axial a_x depth of cut) based on the CCD method (Central Composite Design) consist of 30 test data. Machining uses coated and uncoated carbide tools.

The best mathematical equation results based on RSM for surface roughness prediction using coated tools was quadratic model, and using uncoated tools was linear model. The best mathematical equation results for cutting force prediction using coated tools was quartic model, and using uncoated tools was quadratic model. Optimal conditions for the minimum dependent variable according to RSM were for coated tool V_c = 113.9 m/min, f_z = 0.04 mm/tooth, a_r = 0.27 mm, a_x = 5 mm that obtained R_a = 0137 µm and F_c = 25.29 N. Optimal conditions for

uncoated tool V_c = 125 m/min, f_z = 0.04 mm/tooth, a_r = 0.25 mm, a_x = 5 mm that obtained R_a = 0.161 μm and F_c = 14.89 N.
The best accuracy prediction on ANN with Back Propagation obtained was Levenberg-Marquardt (LM) algorithm. Network structure to achieve the lowest MSE value for surface roughness with coated and uncoated tools were 4-10-1 and 4-13-1, respectively. Network structure to achieve the lowest MSE value for cutting force with coated and uncoated tools were 4-8-1 and 4-10-1, respectively. Based on the MSE value, the accuracy prediction of surface roughness using ANN was better than RSM with coated and uncoated at 62.27% and 93.05%, respectively. The accuracy prediction of cutting force using ANN was better than RSM with coated and uncoated at 99.17% and 96.61%, respectively. The MSE of RSM and ANN both surface roughness and cutting force shows that the prediction were close to the results of the experiment.
Surface roughness was most affected by feed rate. Low feed rates and depth of cut resulted in low surface roughness, but high cutting speeds reduced surface roughness. The cutting force was most affected by the depth of cut. Reduction in depth of cut and feed rate resulted in low cutting forces, but the effect of cutting speed is very small. All dependent variables were lower on non-thin walled machines compared to thin walled machines. The values of cutting force on coated tool are higher than uncoated tool, whereas the surface roughness value of coated tool was lower than uncoated tool and this tendency occurs both in thin-walled and non-thin-walled. All machining conditions used in this study did not cause chatter.

Key words: Ti6Al4V, Thin-walled, MQL, Coconut Oil, RSM and ANN

Citations : 125 (2010 – 2019)

RINGKASAN

PERFORMANCE EVALUATION OF GREEN MACHINING ON THIN-WALLED TI6AL4V USING RESPONSE SURFACE METHODOLOGY AND ARTIFICIAL NEURAL NETWORKS

Karya tulis ilmiah berupa Disertasi, November 2019

Muhammad Yanis; Supervisor Amrifan Saladin Mohruni
Ko-Supervisor Safian Sharif and Irsyadi Yani

Performance Evaluation of Green Machining on Thin-Walled Ti6Al4V using Response Surface Methodology and Artificial Neural Networks.

xxvii + 205 Halaman, 39 Tabel, 58 Gambar, 10 Lampiran

Proses freis komponen berdinding tipis (thin-walled) sangat penting dalam industri penerbangan modern. Komponen *aerospace* membutuhkan material teknik terbaik seperti paduan Ti6Al4V. Paduan ini memiliki banyak keunggulan, namun diklasifikasikan sebagai material yang sulit dilakukan proses pemesinannya. Kemampuan pemesinan yang buruk dari Ti6Al4V berdinding tipis merupakan tantangan. Studi ini juga menjadi penting karena struktur yang rumit dari Ti6Al4V berdinding tipis dan pengaruh fluktuasi gaya pemotongan. Kondisi tersebut menyebabkan getaran yang berpengaruh sulitnya mendapatkan *surface quality* yang diinginkan.

Kebutuhan akan *surface quality* yang baik lebih bijak bila menerapkan pemesinan hijau pada proses freis menggunakan minyak nabati sebagai cairan pemotongan yang tidak beracun dan ramah lingkungan. Minyak kelapa tanpa tambahan campuran dipilih karena sebagai sumber lokal yang baik. Selain itu, dalam upaya untuk meminimalkan harga minyak kelapa dan mahalnya biaya Ti6Al4V, proses pemesinan dilakukan dengan menggunakan teknik *minimum quantity lubrication* (MQL).

Tujuan dari penelitian ini adalah untuk mengevaluasi kinerja pemesinan Ti6Al4V pada *dependent variable* (kekasaran permukaan R_a dan gaya potong F_c). Metode Response Surface Methodology (RSM) dan Artificial Neural Networks (ANN) dikembangkan untuk menentukan prediksi dan optimisasi pemodelan. Variasi nilai *independent variable* (kecepatan potong V_c, gerak makan f_z, kedalaman potong radia a_r dan aksial a_x) berdasarkan metode CCD (Central Composite Design) dengan jumlah 30 data pengujian. Pemesinan menggunakan pahat karbida dengan berpelapis AlCrN (coated) dan tanpa lapis (uncoated).

Hasil persamaan matematika terbaik berdasarkan RSM untuk prediksi kekasaran permukaan menggunakan pahat *coated* adalah model kuadratik, sementara itu untuk pahat *uncoated* adalah model linier. Prediksi gaya potong terbaik untuk pahat *coated* adalah model *quartic* sedangkan untuk paha *uncoated* adalah model kuadratik. Kondisi optimum untuk *dependent variable* minimum menurut RSM untuk kondisi menggunakan pahat lapis adalah V_c = 113.9 m/menit, f_z = 0.04 mm/*tooth*, a_r = 0.27 mm, a_x = 5 mm yang menghasilkan R_a = 0137 µm and F_c = 25.29 N. Kondisi optimum menggunakan pahat tanpa lapis adalah V_c = 125 m/menit, f_z = 0.04 mm/*tooth*, a_r = 0.25 mm, a_x = 5 mm yang menghasilkan kekasaran permukaan (R_a) = 0.161 µm dan gaya potong (F_c) = 14.89 N.

Prediksi akurasi terbaik secara ANN menggunakan *Back Propagation* adalah algoritma *Levenberg-Marquardt (LM)* Struktur jaringan untuk mendapatkan nilai MSE terendah untuk kekasaran permukann kondisi pahat lapis dan pahat tanpa lapis masing-masing adalah 4-10-1 dan 4-13-1. Struktur jaringan untuk untuk gaya potong kondisi pahat lapis dan pahat tanpa apis masing-masing adalah 4-8-1 dan 4-10-1.

Berdasarkan nilai MSE, akurasi prediksi dari kekasaran permukaan menggunakan ANN lebih baik dibandingkan RSM untuk kondisi pahat lapis dan pahat tanpa lapis masing-masing 62,27% dan 93,05%. Akurasi prediksi dari gaya potong menggunakan ANN lebih baik dibandingkan RSM untuk kondisi pahat lapis dan pahat tanpa lapis masing-masing 99,17% dan 96,61%, 62,27% dan 93,05%. Nilai MSE dari RSM dan ANN baik untuk kekasaran permukaan maupun gaya potong menunjukkan bahwa hasil prediksi dekat dengan eksperimen.

Kekasaran permukaan paling dipengaruhi oleh gerak makan. Gerak makan dan kedalaman potong yang rendah menyebabkan kekasaran permukaan yang rendah, namun kecepatan potong yang tinggi juga dapat menghasilkan kekasaran permukaan yang rendah. Gaya potong paling dipengaruhi oleh kedalaman potong. Pengurangan kedalaman potong dan gerak makan menyebabkan berkurangnya gaya potong, sedangan pengaruh kecepatan potong sangat kecil.

Seluruh *dependent variable* lebih rendah nilainya pada pemesinan *non thin-walled* dibandingan pada pemesinan *thin-walled*. Nilai gaya potong menggunakan pahat lapis lebih besar dibanding menggunakan pahat tanpa lapis, namun kekasaran permukaan lebih rendah bila menggunakan pahat lapis dibanding menggunakan pahat tanpa lapis dan kecenderungan ini terjadi baik pada pemesinan *thin-walled* maupun *non-thin-walled*. Seluruh kondisi pemesinan pada yang digunakan dalam studi ini tidak menyebabkan *chatter*.

Kata Kunci : Ti6Al4V, Thin-walled, MQL, Coconut Oil, RSM dan ANN

Kepustakaan : 125 (2010 – 2019)

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Palembang, November 2019

Author

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CHAPTER 1
INTRODUCTION

1.1 Overview

This study evaluated the performance of end milling Ti6Al4V thin-walled using uncoated and coated tools. Machining condition was conducted in minimum quantity lubrication (MQL) with the use of vegetable oil. The influence of independent variables toward dependent variables were determined from mathematical model developed namely response surface methodology (RSM) and artificial neural networks (ANN).

1.2 Background of the Problems

The application of titanium alloys has increased in recent years. This alloys have excellence characteristic such as low density, corrosion resistance and high yield strength, fatigue strength, hardness, toughness (Gupta and Laubscher, 2016; Revuru et al., 2017). Based on the requirements, titanium alloys are ubiquitous applied in the aerospace, automotive, marine, power plant reactor, and consumer electronic in thin-walled structure. Global air traffic is growing fast and prospective main fleet growth is in Asia Pacific. Hence, new aircraft and spare parts demands are also significant. Airframes of aerospace are usually formed by thin-walled Ti6Al4V. Ti6Al4V recently pointed about 60% of the titanium production (Kappmeyer et al., 2012; Garcia and Ribeiro, 2016; Bolar et al., 2018; (Zhu et al., 2019).

Ti6Al4V thin-walled are also an aerospace component as the thin-walled of aluminum alloy, nickel alloy, and stainless steel. Titanium alloys have superior property wherein the density twice lower than nickel alloy and more electrochemical compatible than aluminum. However, titanium is the most popularly difficult manufacturability due to its nature, such high chemical activities and low thermal conductivity (Armendia et al., 2010; Pramanik and Littlefair, 2015; Wstawska and Ślimak, 2016). As an example, thermal conductivity of 7075 aluminum alloy is 25 times higher than that of Ti6Al4V. The cutting tool achieved the head form titanium alloy approximately 80%, whereas only 50% conducted into the tool when machining steel. Another matter faced also because of the low elastic modulus (only 50% of steel) during machining titanium alloys, thereby vibration occur and increases surface roughness (Sharma et al., 2015; Huang et al., 2015; Gupta and Laubscher, 2016; Revuru et al., 2017). Hence, the machining of Ti6Al4V thin-walled is more challenging than that of steel, nickel and aluminum alloys aerospace materials.

The application of cutting fluid is implicated in reducing cutting force when machining titanium alloys. Petroleum-based cutting fluids are extensively used, even though it is noxious on storage and disposal. Asia as the largest consumer of cutting fluids. The International Agency for Research on Cancer (IARC) notified that petroleum-based cutting fluids with main concern are the content of polyaromatic hydrocarbon. This substance is carcinogens, mutagens and teratogens (Pramanik and Littlefair, 2015; Debnath et al., 2019). Investigations estimated the cost of cutting fluid can reach 30% of total cost machining hard materials include the high prices of non-biodegradable disposal treatment (Sharif et al., 2016; Benedicto et al., 2017).

The application of vegetable oil cutting fluids in green machining are intended accordingly renewable, biodegradable and less toxic properties. The polar molecules interact strongly with a metallic surface and enable to absorb pressure in a greater capacity. Moreover, the request for vegetable oil cutting fluids slowly begin to replace the synthetic lubricant (Debnath et al., 2014; Boswell et al., 2017; Jeevan and Jayaram, 2018).

There are several studies on coconut oil, because of its oxidative resistance and better polarity compared to other vegetable oils. Coconut production in Indonesia was more than 2.8 million tons in 2018 (Dirjend_Perkebunan, 2018). The researchers indicated the tendency in reducing, co-efficient of friction, cutting force and surface roughness compared to others vegetable oil or soluble oil. Drilling chips of non thin-walled Ti6Al4V from MQL coconut oil are more uniform, the form didn't become strings and the color didn't show as burnt chip compare than olive oil, sesame oil and palm oil. This indicated that coconut oil as cutting fluids lead to a better cutting mechanism. This better ability is due to the relatively lower viscosity value and greater specific gravity (Banerjee and Sharma, 2015). Studies using nano boric acid and heavy metals in coconut oil as cutting fluid have also been experimented. Unfortunately, European Chemicals Agency (ECHA) classified boric acid and heavy metal as substances of very high concern to the health. Besides, nanoparticle are very expensive (Benedicto et al., 2017; Debnath et al., 2019).

The price of coconut oil, which still relatively high in contrast to petroleum lead the researcher investigated the application soluble cutting fluid of coconut oil. In contrast, in this study coconut oil will be applied as neat oil, according to Srikant and Rao (2017) informed that emulsifier often makes the cutting fluid non-biodegradable. Fairuz et al. (2015) concluded that neat coconut oil is more effective to improve drilling performance under minimum quantity lubrication (MQL).

Latest trends, MQL vegetable oil machining classified as advance green machining. In machining titanium, MQL more suitable for others green machining methods such as cryogenic generates 16 % hardening of Ti6Al4V and dry cutting conduced tool wear (Wstawska and Ślimak, 2016; Debnath et al., 2019). However, it could be intended MQL technique as another effort in minimizing the consumption of cutting fluid which hereinafter reducing the high cost of milling titanium alloy. This take into consideration about the strain hardening in machining titanium alloys make the process very uneconomical. There are some studies about the machining under MQL vegetable oil (Sharma et al., 2015; Sharif et al., 2016; Park et al., 2017).

In this study uncoated tool and AlCrN coated tool was utilized under MQL coconut oil. This is important to consider about the effect of tool type in machining titanium alloy. Uncoated carbide and AlCrN coated tool as typical tool in milling of Ti6Al4V (Wstawska and Ślimak, 2016; Gupta and Laubscher, 2016).

Many studies have been carried out that implement RSM and ANN. Rao and Kalyankar (2014) informed in the review about studies that employed RSM and ANN in evaluating surface roughness when machining various materials such as steel, composite, alloy etc. The RSM was utilized in formulating the problem consist based on mathematical regression. Mia and Dar, 2016 claimed that the accuracy of ANN predictive was better compare to RSM when dry turning AISI 1060. Whereas Mia et al (2017) obtained that the accuracy RSM predictive was better than ANN in cryogenic turning Ti6Al4V. Based on considering the previous investigations, there are lots of problems in the machining of Ti6Al4V. The evaluation and optimization of this milling study were obtained with the use of RSM and ANN.

1.3 Statement of The Problems

Milling of thin-walled components is very substantial in the modern aerospace industry. The machining of Ti6Al4V thin-walled is more difficult and challenging than that of steel, nickel and aluminium alloys as aerospace materials. Important independent variables are learned in machining Ti6Al4V straight to elevate dependent variables such cutting force, followed by the increase in vibration and contributes to poor surface roughness. The complexity of machining thin-walled Ti6Al4V requires the support of cutting fluids that meet these specific needs. In spite of petroleum-based cutting fluids are extensively used, it is harmful in use, storage and disposal. Coconut oil as excellent vegetable oil was used as cutting fluids. Thereafter in effort to minimize the price of coconut oil and the high cost of machining Ti6Al4V then milling operation obtained by the utilization of MQL technique. It is necessary to consider about the influence of tool type to dependent variables. Hence, either coated AlCrN tool or uncoated carbide tool were compared in this study, at once it can be discussed in relation to machining variables. It is notable that lots of problems in the milling of Ti6Al4V. Therefore it was required to formulation the problem with the modelling and optimization of machining by RSM and ANN.

1.4 Objectives of The Study

The objectives of this study are listed below:

1. To determine the mathematical models of RSM for end milling on thin-walled Ti6Al4V with coated and uncoated tools.
2. To reveal the RSM optimum machining conditions in end milling of Ti6Al4V under MQL with coated and uncoated tools.
3. To determine the best prediction accuracy algorithm according to ANN.
4. To compare closeness to experimental according to mean square error (MSE) values on the RSM model and the accuracy of ANN predictions.
5. To determine the influence of independent variables to dependent variables with coated and uncoated tools.
6. To determine the effect of thin-walled and non-thin-walled structures on surface roughness, cutting force and vibration with coated and uncoated tools.

1.5 Significance of The Study

The significance of this study is to investigate the parameters of machining during milling advanced aerospace materials in thin-walled structure with the application of neat coconut oil as best locally source vegetable oil. The milling Ti6Al4V obtained under healthy machining, but still along inexpensive machining operation.

This study is also significant since there are very rarely found in the evaluation of performance machining which concern to the link between the utilization of vegetable oil cutting fluid and the application of statistical technique either mathematical terminology (RSM) or computational modeling tool (ANN).

1.6 Scopes of The Study

The scope of this study is to evaluate the performance of end milling on thin-walled Ti6Al4V alloys. This process will be conducted under MQL-system of neat coconut oils 40 mL/hour. Various independent variables were cutting speed-V_c (64 to 156 m/min), feed rate-f_z (0.025 to 0.158 mm/tooth), radial-a_r (0.2 to 0.51 mm) and axial-a_x (3.5 to 14.14 mm) depth of cut (DOC). The dependent variables investigated were surface roughness (R_a), cutting force (F_c) and vibration. The methods that approaches for finding the prediction model and optimum cutting condition, RSM and ANN would be involved.

1.7 Conceptual Framework

The poor rigidity of thin section in thin-walled structure prone to deform by the influence of cutting force (Bolar et al., 2018b). It is difficult to improve the productivity in milling thin-walled Ti6Al4V since a moderate raise of depth of cut and feed rate straight to elevate dependent variables cutting force, followed by the increase in vibration and contributes to higher surface roughness (Park et al., 2017, Jiang et al., 2017). In previous studies, the main factors affecting surface roughness were cutting speed and feed rate (Grzesik, 2017; Park et al., 2017). Whereas the cutting speed and depth of cut of affects vibrations more (Wang et al., 2014; Wu et al., 2016). Furthermore, the feature of this alloy such as strain hardening and complex deformation also brings about to the higher cutting force (Pramanik and Littlefair, 2015). Besides, the hardening of these alloys also caused by its high reactivity with interstitial oxygen, which form oxide film (Adamus et al., 2018). Huang et al (2015) also discussed that serrated chips from the surface of a workpiece which occur as typical characteristics of milling titanium alloy thin-walled will generate the higher cutting force, vibration and deterioration of surface finish. Proper surface quality is purposed for corrosion resistance, fatigue strength and the aesthetic.

Application of cutting fluid is implicated in reducing cutting force during machining titanium alloy (Debnath et al., 2015; Debnath et al., 2019). When MQL coconut oil was used as a cutting fluid, the chips of non thin-walled Ti6Al4V drilling would be better than the use of others vegetable oil (Banerjee and Sharma, 2015). Uncoated carbide and AlCrN coated tool as typical tool in milling Ti6Al4V (Gupta and Laubscher, 2016). The trend of phenomena may not occur the same if machining is carried out on different types of tools. Therefore, studies are needed which further discuss the effect of the independent variables applying coconut oil as MQL cutting fluid to other related dependent variables by utilizing uncoated and AlCrN coated tool in milling Ti6Al4V thin-walled. This conceptual framework can be presented in a scheme according to the Figure 1.1.

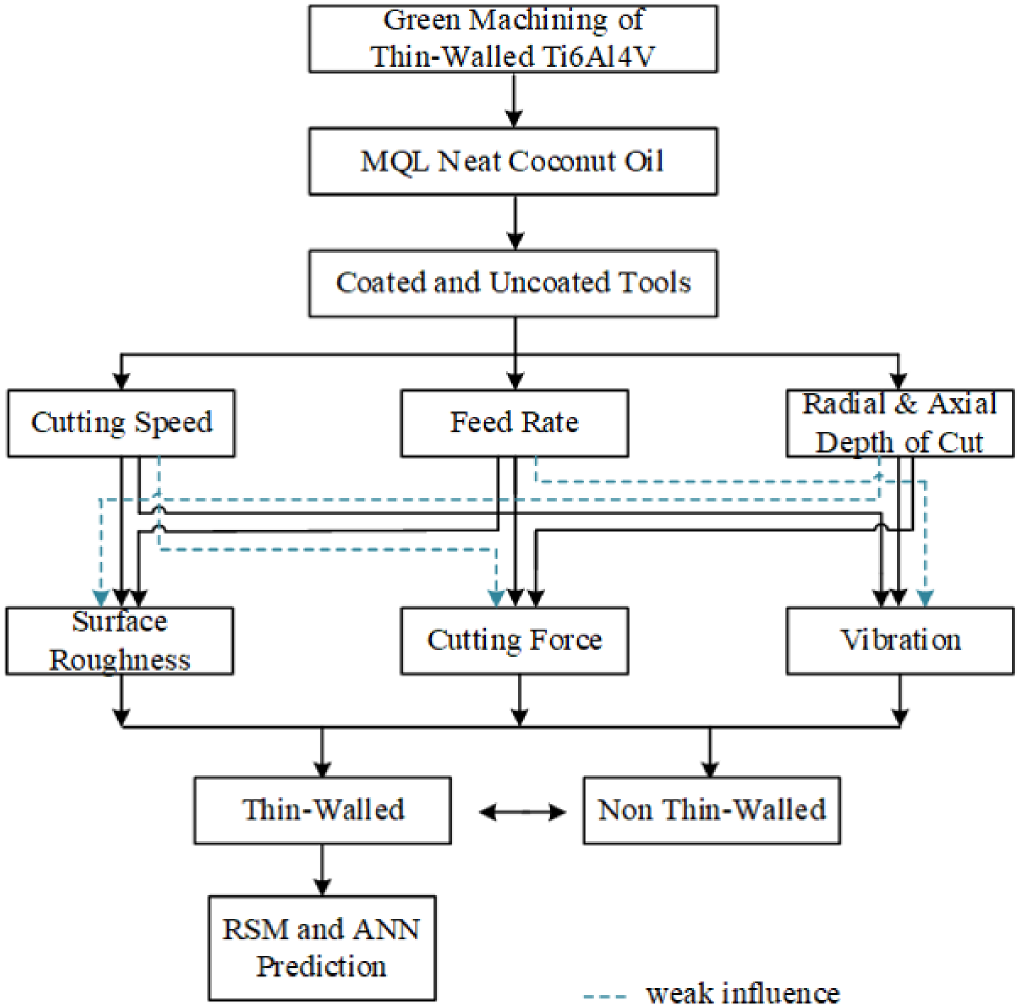

Figure 1.1 Conceptual framework in study

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