

**INVESTIGATION OF TOOLTIP TEMPERATURE AND
SURFACE ROUGHNESS IN TURNING OF AISI 1045
STEEL WITH COCONUT OIL-BASED HYBRID
NANOFLUID UNDER MQL TECHNOLOGY**

Viraj Niroshan Abeweera

(198400A)

Degree of Master of Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

November 2022

**INVESTIGATION OF TOOLTIP TEMPERATURE AND
SURFACE ROUGHNESS IN TURNING OF AISI 1045
STEEL WITH COCONUT OIL-BASED HYBRID
NANOFLUID UNDER MQL TECHNOLOGY**

Viraj Niroshan Abeweera

(198400A)

Dissertation submitted in partial fulfilment of the requirements for the
Master of Engineering in Manufacturing Systems Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

November 2022

Declaration

I declare that this is my work, and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning, and to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant the University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part, in print, electronic or other mediums. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date:

The above candidate has carried out research for the master's thesis under my supervision.

Name of the supervisors: Dr. G.I.P. Perera
Dr. H.K.G. Punchihewa
Mr. R.K.P.S. Ranaweera

Signature of the supervisor: Date:

Name of the supervisor: Dr. G.I.P. Perera 18.11.2022

Signature of the supervisor: Date: [18/11/2022](#)

Name of the supervisor: Dr. H.K.G. Punchihewa

Signature of the co-supervisor: Date:

Name of the co-supervisor: Mr. R.K.P.S. Ranaweera

Dedication

To the most courageous individuals who guided me to great accomplishments: my beloved mother, *Nandanie Sumanarathna* and my wife, *Bimba Veenavi Yoshinika*

Acknowledgement

As a graduate student in the Faculty of Engineering at the University of Moratuwa, I had to complete a research project in partial fulfilment of the Manufacturing Systems Engineering Master of Engineering degree requirements. I chose " Investigation of tooltip temperature and surface roughness in turning of AISI 1045 steel with novel coconut oil-based hybrid nanofluid under MQL technology" as my topic. I am incredibly grateful to the University of Moratuwa for providing this opportunity. I would like to thank Dr G.I.P. Perera, Dr. H.K.G. Punchihewa, and Mr. R.K.P.S. Ranaweera for their guidance, constant supervision, and provision of project-related information and for their assistance in completing this research project. Their cooperation and encouragement motivated me to finish this project. In addition, I appreciate Mrs. M. Hennayake (QA manager @ CSCL) and Mr. M.M.L.C. Malmessa (DGM of technical @ CSCL) for their insightful comments and for giving extra support to complete my research. I would also like to express my sincere appreciation and gratitude to the University of Ruhuna for providing me with information, time, and engineering workshop facilities for the research. My gratitude and appreciation also goes to my project development colleagues and those who have voluntarily assisted me with their skills.

Abstract

Over the past few years, positive changes have occurred in the manufacturing industry and many other fields as a direct result of current breakthroughs in nanotechnology. The integration of nano-sized solid lubricants into aerosols, suspensions, and emulsions can lead to an enhancement of the end product's tribological and thermal properties. This is because of the constituent materials' unique chemical and physical properties. Therefore, this makes it possible for lubricants or coolants to perform their functions to attain a high level of productivity in machining processes.

This study aimed to investigate the effect on average surface roughness and tooltip temperature in turning AISI 1045 steel with novel coconut oil-based hybrid nanofluid under MQL technology. Al_2O_3 and TiO_2 were chosen as the two nanoparticles to use in the experiments after conducting a survey of the relevant research in the field. In order to reach this aim, Taguchi's L16 orthogonal array, which is comprised of four factors, was utilized. Concentrations of Al_2O_3 , TiO_2 , cutting speed, and air pressure are the four factors considered in this study. In this experimental design, the responses considered were average surface roughness and the temperature of the tooltip. Using the Minitab 17 software, the model fitting and optimization were carried out. The values that recorded as being optimal were,

- 0.75 wt. % of Al_2O_3 ,
- 0.00 wt. % of TiO_2 ,
- 2.5 bar of air pressure,
- 96 m/ min of cutting speed

As a direct consequence, it is clear that the developed MWFs show significantly higher performance than the other two techniques, dry cutting and coconut oil-based MQL cooling. The percentages show a 23.92 % and 37.97 % reduction in tooltip temperature compared to dry cutting conditions for MQL+ CC and Nano+ MQL+CC conditions, respectively. Also, the average surface roughness was reduced by 33.87 % and 94.85 % compared to dry cutting conditions for MQL+ CC and Nano+ MQL+CC conditions, respectively. For future work, we can use thermophysical and tribological factors rather than cost as a determining factor for better results.

Keywords: Minimum quantity lubrication/ nanoparticle/ machining/ surface roughness/ tooltip temperature

Table of contents

	Page
Declaration	i
Dedicationii
Acknowledgments.....	iii
Abstract	iv
Table of content	v
List of Figures	viii
List of Tablesxi
List of abbreviations.....	.xii
List of Appendices.....	.xiii
1 CHAPTER: INTRODUCTION	1
1.1 Aim.....	5
1.2 Objectives.....	6
1.3 Methodology	6
1.4 Thesis Overview.....	8
2 CHAPTER: LITERATURE REVIEW	9
2.1 Evolution of Cooling/ Lubricating and MWF.....	9
2.1.1 Cooling and Lubricating	9
2.1.2 Metal Working Fluid.....	13
2.2 Machining with Vegetable Oil-Based Nanofluids	13
2.2.1 Turning.....	13
2.2.2 Milling.....	17
2.2.3 Drilling	18
2.3 Nanoparticles with Base Fluid	25
2.4 Effects of Machining Parameters on Responses	28

2.4.1	Cutting Parameters	28
3	CHAPTER: METHODOLOGY	31
3.1	Base Fluid Preparation	31
3.2	Nanoparticle Selection for Experiment	32
3.3	Nanofluid Preparation	33
3.4	Machine and Equipment.....	36
3.4.1	Workpiece	36
3.4.2	Machine and Tool	37
3.5	Experimental Design	39
4	CHAPTER: RESULTS AND DISCUSSION.....	45
4.1	Experimental Results.....	45
4.2	Data Analysis- ANOVA.....	49
4.2.1	Sum of Squares	50
4.2.2	Mean Squares	54
4.2.3	Main Effect Plot	54
4.3	Interpretation of Results	56
4.3.1	Tooltip Temperature.....	56
4.3.2	Average Surface Roughness	57
4.3.3	Plots of Main Effects for Responses	58
	Result Table for T_{tip}	58
	Result Table for R_a	59
4.4	Model Fitting and Optimization.....	60
4.4.1	Model Fitting.....	60
4.4.2	Model Validation	74

Validation for T_{tip}	74
Validation for R_a	76
4.4.3 Multi-Objective Optimisation.....	77
Desirability Function.....	78
Validation of Results.....	80
5 CHAPTER: CONCLUSION.....	85
REFERENCES.....	88
LIST OF APPENDICES.....	109

List of Figures

	Page
Figure 1-1: The superior biodegradability of vegetable oils over mineral oils [25]	3
Figure 1-2: Popularity of green solution [25]	4
Figure 1-3: Market share of MCFs in the United States in Billions [25].....	4
Figure 1-4: Present and future direction of nanofluids [37].....	5
Figure 1-5: Research methodology	7
Figure 1-6: Thesis flow	8
Figure 2-1: Techniques for the reduction in heat generation during turning [38]	10
Figure 2-2: Classification of nanomaterials [44]	12
Figure 2-3: Cutting fluid classification [10].....	13
Figure 2-4: Graphical representation of different mechanisms involved with nano - lubricant [113].....	26
Figure 2-5: Factors affecting surface roughness and tool temperature	28
Figure 3-1: Base fluid preparation; [a]- Preparing of PGPR and TWEEN 80 mixture; [b]- Adding coconut oil into the pre- prepared mixture and stirring; [c]- Adding water into pre- prepared mixture	31
Figure 3-2: Preparation methods (a) One-step method (b) Two-step method [131].....	33
Figure 3-3: Nanofluid preparation steps	35
Figure 3-4: Prepared samples.....	35
Figure 3-5: Work piece (AISI 1045).....	36
Figure 3-6: Model 6241X1000 lathe machine	37
Figure 3-7: Mitsubishi CNMG 120408- MS VP15TF tool tip	38
Figure 3-8: MWFs and tool arrangement.....	38
Figure 3-9: Depth of cut and Flank wear behaviour in medium carbon turning [151]....	40
Figure 3-10: Feed and Flank wear relationship in medium carbon turning [151]	41
Figure 3-11: Setup arrangement.....	44
Figure 4-1: Factor plot tooltip temperature for AISI 1045	56

Figure 4-2: Factor plot surface roughness for AISI 1045	57
Figure 4-3: Main effects plot for the mean of T_{tip}	58
Figure 4-4: Main effects plot for the mean of R_a	59
Figure 4-5: Temperature of the tooltip as a function of Al_2O_3 concentration and TiO_2 concentration.....	62
Figure 4-6: Temperature of the tooltip as a function of Al_2O_3 concentration and air pressure	63
Figure 4-7: Temperature of the tooltip as a function of Al_2O_3 concentration and cutting speed.....	64
Figure 4-8: Temperature of the tooltip as a function of TiO_2 concentration and air pressure	65
Figure 4-9: Temperature of the tooltip as a function of TiO_2 concentration and cutting speed.....	66
Figure 4-10: Temperature of the tooltip as a function of air pressure and cutting speed.....	67
Figure 4-11: Average surface roughness as a function of Al_2O_3 concentration and TiO_2 concentration.....	68
Figure 4-12: Average surface roughness as a function of Al_2O_3 concentration and air pressure	69
Figure 4-13: Average surface roughness as a function of Al_2O_3 concentration and cutting speed.....	70
Figure 4-14: Average surface roughness as a function of TiO_2 concentration and air pressure	71
Figure 4-15: Average surface roughness as a function of TiO_2 concentration and cutting speed.....	72
Figure 4-16: Average surface roughness as a function of air pressure and cutting speed.....	73
Figure 4-17: Empirical results vs Experiment model for T_{tip}	75
Figure 4-18: Empirical results vs Experiment model for R_a	77
Figure 4-19: Multi-objective optimization results	79
Figure 4-20: Cooling condition comparisons.....	83

Figure 4-21: Performance comparison (%).....84

List of Tables

	Page
Table 2-1: Literature to select nanoparticles	21
Table 2-2: Thermal conductivity of materials.....	27
Table 3-1: Selected five nanoparticles	32
Table 3-2: Price comparison of selected nanoparticles [130]	33
Table 3-3: Al ₂ O ₃ and TiO ₂ particle content	35
Table 3-4: Chemical composition of AISI 1045	36
Table 3-5: Mechanical properties of AISI 1045	37
Table 3-6: Machining parameters and their levels	42
Table 3-7: Standard L16 (4 ⁴) Orthogonal Array	42
Table 4-1: Observed temperature results from the thermal infrared camera	45
Table 4-2: Observed R _a results from TR200 surface roughness	48
Table 4-3: L16 Orthogonal Array for responses and variables values.....	49
Table 4-4: First stage data calculation for tool temperature	53
Table 4-5: First stage data calculation for surface roughness	53
Table 4-6: Derived ANOVA for T _{tip}	56
Table 4-7: Derived ANOVA for R _a	57
Table 4-8: Derived response table for means of T _{tip}	58
Table 4-9: Derived response table for means of R _a	59
Table 4-10: Average error percentage for T _{tip}	75
Table 4-11: Average error percentage for R _a	76
Table 4-12: Optimized input variables for the response parameters.....	79
Table 4-13: Confirmatory experiment result for T _{tip}	81
Table 4-14: Confirmatory experiment result for R _a	81
Table 4-15: Summary of confirmatory experiment results	81
Table 4-16: Dry and MQL+ CC machining for optimum T _{tip}	82
Table 4-17: Dry and MQL+ CC machining for optimum R _a	82

List of abbreviations

Abbreviation	Description
AISI	American Iron and Steel Institute
Al ₂ O ₃	Aluminium oxide
ANOVA	Analysis of variance
CC	Coconut Oil
CSCL	Ceylon Steel Corporation Limited
DOE	Design of Experiments
FOE, UOR	Faculty of Engineering, University of Ruhuna
FNG	Functionalized Nano Graphite
MCF	Metal Cutting Fluid
MOO	Multi-objective optimization
MQL	Minimum Quantity Lubrication
MWF	Metal Working Fluid
NBA	Nano Boric Acid
NDM	Near Dry Machining
NG	Nano Graphite
OA	Orthogonal Array
PGPR	Polyglycerol polyricinoleate
Ra	Average Surface Roughness
T _{tip}	Tool tip temperature
TiO ₂	Titanium dioxide
VB	Flank wear

List of Appendices

Appendix	Description	Page
Appendix - A	ANOVA calculation for Tooltip Temperature.....	109
Appendix - B	ANOVA calculation for Average Surface Roughness.....	110
Appendix - C	Model fitting for Tooltip Temperature.....	111
Appendix - D	Model fitting for Average Surface Roughness.....	113