PERFORMANCE OF COOLANT STRATEGIES WHEN TURNING HARDENED MARTENSITIC STAINLESS STEEL USING TIALN COATED CARBIDE TOOL

AMAD ELDDEIN ISSA MOHAMED ELSHWAIN

UNIVERSITI TEKNOLOGI MALAYSIA

PERFORMANCE OF COOLANT STRATEGIES WHEN TURNING HARDENED MARTENSITIC STAINLESS STEEL USING TIALN COATED CARBIDE TOOL

AMAD ELDDEIN ISSA MOHAMED ELSHWAIN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

OCTOBER 2017

To my dearest father and mother, my lovely wife, and my lovely children for their never-ending love, patience and support

ACKNOWLEDGEMENT

First of all, I would like to thank **Allah SWT** for giving me strength and endless courage for the successful completion of this research work. My sincere thanks to my philosophers and research supervisors **Dr. Norizah Redzuan and Professor Dr. Noordin Mohd Yusof**, for helping me in choosing this research topic and guiding me throughout the work. Without their initiation, encouragement and directions, this research would not have taken shape. They are the motivation factor for the successful completion of this work

My sincere thanks are also due to **Mr. Aidid and Mr. Sazali** of the Production Laboratory who have helped me for the successful completion of the experimental works. It is my privilege to thank all the staff at the Faculty of Mechanical Engineering for their technical support and also thank all my colleagues who have helped me directly or indirectly in my research work.

I would like to express my sincere and wholehearted gratitude to my parents, for their endless love, support, guidance, and inspiration throughout my life. Without their encouragement, I would not able to achieve everything I have today. They are and always will be my source of strength and courage. A heartfelt gratitude also goes to my brothers, sisters for their care and love.

And last, but not least, I would like to give special thanks to my beloved wife, for being extremely supportive during PhD study. My life would not be so beautiful without her love. Thanks to my lovely children, Ahmed, Mohamed and Issa for brining endless happiness into my family

ABSTRACT

Coolant strategies in turning hardened stainless steel are important, due to the fact that heat cannot be removed efficiently from the cutting area. This heat issue shortens the tool life and reduces machined surface integrity, resulting in higher machining cost and lower productivity. Conventional cutting fluids cause health problems, workshop pollution and higher recycling cost. Dry, minimum quantity lubricant (MQL) and cryogenic machining are alternatives of green coolant to eliminate conventional cutting fluids. Thus, the objective of this research is to study the feasibility and performance of using new green coolant strategies that contribute to the sustainable process. Experiments were carried out in two different stages when turning 48 ±1 HRC martensitic stainless steel (AISI420) uses a wiper PVD-TiAlN coated carbide cutting tool. Cutting speeds (100, 135, and 170 m/min) and feed rates (0.16, 0.2, and 0.24 mm/rev) were investigated. The depth of cut was kept constant at 0.2 mm. Nitrogen gas pressure was 0.5 MPa and the oil mist (castor oil) flow rate was 40 ml/h. In the first stage, comparison between three cutting conditions were evaluated, namely cold nitrogen gas (cold N_2), nitrogen gas with oil mist (N_2+MQL) and cold nitrogen gas with oil mist conditions (cold N_2+MQL). Dry cutting was used as the benchmark. In the second stage, the best cutting condition from first stage was used for further experiments to investigate the effect of cutting speed and feed on machining responses such as tool life (T_L), volume of material removed (VMR), surface roughness (Ra) and cutting forces (Fx, Fy and Fz), chip morphology and microstructures of machined surface. Full factorial design was used to model the relationship between cutting responses (tool life, surface roughness, and cutting forces) and different cutting speeds and feed rates. These models were verified by performing confirmation experiments. The results obtained showed that cold N_2+ MQL improved performance in terms of tool life, surface roughness and cutting forces in comparison to dry, cold N_2, and N_2+MQL conditions. At cutting speed of 100 m/min and feed rate of 0.16 mm/rev, cold N_2+MQL condition prolongs the tool life by 135%, decreases the cutting forces by 18%, and improves surface roughness by 19% as compared to dry cutting. Flank and crater were observed at the tool nose. Abrasion and adhesion were the dominant wear mechanisms when turning hardened martensitic stainless steel. The machined surface had less alteration of grain microstructure and higher hardness in cold N_2+MQL condition compared to the dry cutting condition. The longest tool life was obtained at low cutting speed and low feed rate, whereas lower cutting forces and better surface roughness were observed at high speed and low feed rate. Analysis based on the mathematical models of machining responses (tool life, surface roughness and cutting forces) would be helpful in selecting cutting variables for optimization of turning hardened stainless steel, which is in line with sustainable and green machining by using cold N_2+MQL condition.

ABSTRAK

Strategi bahan penyejuk dalam melarik keluli keras tahan karat adalah penting disebabkan oleh haba yang terhasil sukar dialir keluar dari kawasan pemotongan. Masalah ini memendekkan hayat matalat dan mengurangkan integriti permukaan dimesin mengakibatkan kos pemesinan yang lebih tinggi dan produktiviti yang lebih rendah. Cecair pemotongan konvensional menimbulkan masalah kesihatan, pencemaran bengkel dan kos kitar semula yang tinggi. Pemesinan kering, pelincir kuantiti minimum (MQL) dan pemesinan sejuk-lampau adalah alternatif penyejukan hijau untuk menggantikan cecair pemotongan konvensional. Oleh itu, objektif kajian ini adalah untuk mengkaji kesauran dan prestasi penggunaan strategi baru penyejukan hijau yang menyumbang kepada kelestarian proses. Ujikaji dilakukan dalam dua peringkat berbeza dengan melarik keluli tahan karat martensitit (AISI 420) 48 ±1 HRC menggunakan alat memotong pengelap PVD-TiAlN salutan karbida. Kelajuan pemotongan (100, 135, and 170 m/min) dan kadar suapan (0.16, 0.2, dan 0.24 mm/putaran) dikaji. Kedalaman potongan dikekalkan malar pada 0.2 mm. Tekanan gas nitrogen adalah 0.5 MPa dan kadar alir kabus minyak (kastor) adalah 40 ml/jam. Pada peringkat pertama, perbandingan antara tiga keadaan pemotongan telah dinilai, iaitu gas nitrogen sejuk (*cold* N_2), gas nitrogen dengan kabus minyak (N_2+MQL), dan keadaan gas nitrogen dengan kabus minyak sejuk (*cold* N_2+MQL). Pemotongan kering digunakan sebagai tandaras. Pada peringkat kedua, keadaan pemotongan terbaik dari peringkat pertama telah digunakan untuk mengkaji kesan kelajuan pemotongan dan suapan keatas tindakbalas pemesinan seperti hayat alat (T_L), isipadu pembuangan bahan (VMR), kekasaran permukaan (Ra), daya pemotongan (Fx, Fy dan Fz), morfologi serpihan dan mikrostruktur permukaan yang dimesin. Rekabentuk pemfaktoran penuh telah digunakan untuk memodel hubungan antara tindakbalas pemotongan (hayat alat, kekasaran permukaan, dan daya pemotongan) dan kelajuan pemotongan dan kadar suapan yang berbeza. Model-model ini telah disahkan dengan melakukan ujikaji pengesahan. Hasil kajian menunjukkan bahawa keadaan N_2+MQL sejuk meningkatkan prestasi dari segi hayat alat, kemasan permukaan dan daya pemotongan berbanding pemotongan kering, N_2 sejuk, dan keadaan N_2+MQL. Pada kelajuan pemotongan 100 m/min dan kadar suapan 0.16 mm/putaran, keadaan N_2+MQL sejuk memanjangkan hayat alat sebanyak 135%, mengurangkan daya pemotongan sebanyak 18%, dan memperbaiki kekasaran permukaan sebanyak 19% berbanding dengan pemotongan kering. Hausan rusuk dan kawah telah diperhatikan pada muncung matalat. Lelasan dan lekatan adalah mekanisma haus utama pada matalat pemotong apabila melarik keluli keras tahan karat martensitit. Permukaan yang dimesin mengalami kurang perubahan mikrostruktur bijian dan peningkatan kekerasan bagi keadaan N_2+MQL sejuk berbanding dengan pemotongan kering. Hayat matalat terpanjang dicapai pada kelajuan pemotongan rendah dan kadar suapan rendah manakala daya pemotongan rendah dan kekasaran permukaan terbaik diperhatikan pada kelajuan tinggi dan kadar suapan rendah. Analisa model matematik bagi tindakbalas permesinan (hayat matalat, kekasaran permukaan dan daya pemotongan) boleh membantu mengoptimakan pemilihan pembolehubah melarik keluli keras tahan karat selaras dengan pemesinan lestari dan hijau dengan menggunakan keadaan N_2+MQL sejuk.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xii
	LIST OF FIGURES	xv
	LIST OF ABBREVIATIONS	xxv
	LIST OF APPENDICES	xxvii
1	**INTRODUCTION**	**1**
	1.1 Overview	1
	1.2 Problem Statement	4
	1.3 Objectives	6
	1.4 Scope of Study	6
	1.5 Organization of Thesis	7
	1.6 Significant of This Study	8
2	**LITERATURE REVIEW**	**9**
	2.1 Metal Cutting	9
	2.2 Chip Morphology	11

2.2.1 Effect of Cutting Parameters on Chip Morphology 14

2.2.2 Chip Formation under Coolant/Lubricant Conditions 15

2.2.3 Measurements of Chip Formation 16

2.3 Hard Turning 19

2.4 Stainless Steel 21

2.4.1 Ferritic Stainless Steel 22

2.4.2 Martensitic Stainless Steel 22

2.4.3 Austenitic Stainless Steel 23

2.4.4 Duplex Stainless Steel 23

2.5 Cutting Tool 24

2.5.1 Tool Materials of Hard Turning 25

2.5.1.1 Cemented Carbide 26

2.5.1.2 Ceramics 28

2.5.1.3 Cubic Boron Nitride (CBN) 28

2.5.1.4 Polycrystalline Diamond (PCD) 29

2.5.1.5 Coated Tools 29

2.5.2 Geometry of Single-Point Cutting Tool 31

2.6 Cutting Fluids 34

2.6.1 Conventional Metal Cutting Fluids 34

2.6.1.1 Water-Soluble Cutting Fluids 35

2.6.2.2 Oil-Based Cutting Fluids 36

2.7 General Issues in Application of Conventional Cutting Fluids 37

2.8 Environmentally Friendly Machining Techniques 39

2.8.1 Dry Cutting 39

2.8.2 Minimum Quantity Lubrication (MQL) Technique 39

2.8.3 Cryogenic Machining 42

2.8.4 Gas-Based Cooling 44

2.8.4.1 Vortex Tube 47

2.8.4.2 Vapour-Compression Refrigeration 48

	2.8.5	Cryogenic Minimum Quantity Lubrication Technique (CMQL)	50
	2.9	Tool Life and Tool Wear	55
	2.9.1	Flank Wear	56
	2.9.2	Crater Wear	57
	2.9.3	Tool Wear Mechanisms	58
	2.9.3.1	Abrasive Wear	59
	2.9.3.2	Adhesion Wear	60
	2.9.3.3	Diffusion Wear	62
	2.9.3.4	Oxidation Wear	63
	2.10	Surface Integrity	66
	2.10.1	Surface Roughness	66
	2.10.2	Microstructure of Machined Surface	69
	2.10.3	Microhardness of Machined Surface	71
	2.10.4	Residual Stress	72
	2.11	Cutting Forces	73
	2.12	Cutting Temperatures	75
	2.12.1	Cutting Temperature Measurement	77
	2.13	Optimization Method for Metal Cutting Processes	81
	2.14	Literature Summary	83
3		**RESEARCH METHODOLOGY**	**84**
	3.1	Introduction	84
	3.2	Experimental Conditions	88
	3.3	Experimental Procedures	89
	3.4	Work Material, Machine Tool and Cutting Tool	90
	3.4.1	Workpiece Material	90
	3.4.2	CNC Machine Tool	91
	3.4.3	Cutting Tool	92
	3.5	Coolant/Lubrication Conditions	93
	3.5.1	Cold Nitrogen Gas System	93
	3.5.2	Nitrogen Gas with Oil Mist System	95
	3.5.3	Cold Nitrogen Gas with Oil Mist System	97

		3.5.4 Air Dryer System	98
		3.5.5 Process Description of Air Dryer	98
	3.6	Measurement Instruments and Test Methods	100
		3.6.1 Tool Wear	100
		3.6.1.1 Tool Wear Criteria	101
		3.6.2 Surface Roughness	102
		3.6.3 Microstructure and Microhardness of Machined Surface	102
		3.6.4 Cutting Forces	104
		3.6.5 Cutting Temperature	106
		3.6.6 Chip Morphology	107
	3.5	Design of Experiments	108
4		**RESULTS AND DISCUSSION**	**110**
	4.1	Introduction	110
	4.2	Comparison Study of Dry, Cold N_2, N_2+MQL, and Cold N_2+MQL Conditions	110
		4.2.1 Tool life (T_L) and Volume of Material Removed (VMR)	111
		4.2.2 Tool Wear	114
		4.2.3 Surface Roughness (Ra)	117
		4.2.4 Cutting Forces	119
		4.2.5 Cutting Temperature	123
	4.3	Cold Nitrogen with Oil Mist (cold N_2+MQL) Condition	127
		4.3.1 Tool Life and Volume of Material Removed	127
		4.3.2 Tool Wear	129
		4.3.2.1 Tool Wear Mechanism	133
		4.3.3 Surface Integrity	139
		4.3.3.1 Surface Roughness	139
		4.3.3.2 Microstructure of Machined Surface	142
		4.3.3.3 Microhardness of Machined Surface	144
		4.3.4 Cutting Forces	146

4.3.5 Chip Morphology 149

4.3.5.1 Effects of Cutting Parameters on Peak and Valley Saw-Tooth Chip Height 161

4.3.5.2 Effects of Cutting Parameters on Tooth Pitch 162

4.3.5.3 Effects of Cutting parameters on Saw Tooth Chip Angle (Θ_1) 163

4.7.5.4 Effects of Cutting Parameters on Crack Initiation Angle (Θ_2) 163

4.7.5.5 Effects of Cutting Parameters on Degree of Segmentation (Gs) 164

4.7.5.6 Effect of Cutting Parameters on Saw-Tooth Segmentation Frequency 165

5 DEVELOPMENT OF MATHEMATICAL MODEL FOR MACHINING RESPONSES 168

5.1 Overview 168

5.2 Tool Life Model 169

5.3 Volume of Material Removed Model 173

5.4 Surface Roughness Model 178

5.5 Cutting Forces Model 182

5.6 Optimization of Cutting Condition 191

5.7 Summary 192

6 CONCLUSIONS AND FUTURE WORK 194

6.1 Comparison between Dry, Cold Nitrogen Gas, Nitrogen with Oil Mist and Cold Nitrogen with Oil Mist Conditions 194

6.2 Cold Nitrogen with Oil Mist Condition 195

6.3 Recommendations for Future Work 197

REFERENCES 198

Appendices A-F 218-224

LIST OF TABLES

TABLE NO	TITLE	PAGE
2.1	Cutting tools properties (Davim, 2008)	24
2.2	Classification of carbides according to use (Davim, 2008)	27
2.3	Advantages and disadvantages of vegetable oils as lubricants (Shashidhara and Jayaram, 2010)	38
2.4	Physical properties of nitrogen phases (Weisend and Weisend, 1998)	43
2.5	Summary of studies on gases coolant and lubricants when turning different types of steel alloys	53
2.6	Flank wear (VB_B) range in industrial practice for different cutting tool materials (Davim, 2008)	56
3.1	Experimental condition (first stage)	88
3.2	Experimental condition (second stage)	88
3.3	Chemical contents hardened martensitic stainless tool steel (AISI 420)	90
3.4	Physical and mechanical properties of hardened martensitic stainless tool steel AISI 420 (Uddeholm, 2004)	91
3.5	Physical and chemical properties of castor oil (Pop *et al.*, 2008, Joseph *et a*l., 2007)	96
3.6	Design matrix for the experimental conditions	109
4.1	Tool life and volume of material removed under four coolant/lubricant conditions	112
4.2	The average cutting forces (N) under four coolant/lubricant conditions	120

4.3	Experimental results of tool life and volume of material removed under cold nitrogen gas and oil mist condition (second stage)	128
4.5	Average surface roughness results under cold N_2+MQL condition	140
4.6	Experimental results for cutting forces under cold N_2+MQL condition	147
5.1	Experiments design layout	169
5.2	Experimental results of tool life and volume of material removed (VMR) under cold nitrogen gas and oil mist condition	170
5.3	Sequential model sum of squares for tool life data	171
5.4	Analysis of variance for quadratic model of tool life	172
5.5	Sequential model sum of squares for VMR data	174
5.6	Analysis of variance for quadratic model of VMR	175
5.7	Experimental results of surface roughness under cold N_2+MQL condition	178
5.8	Sequential model sum of squares for surface roughness data	179
5.9	Analysis of variance for quadratic model of surface roughness data	180
5.10	Experimental results for cutting forces under cold N_2+MQL condition	183
5.11	Sequential model sum of squares for feed force (Fx) data	183
5.12	Analysis of variance for linear model of feed force (Fx)	184
5.13	The sequential model sum of squares for the tangential force (Fy) data	184
5.14	Analysis of variance for quadratic model of tangential force (Fy)	185
5.15	The sequential model sum of squares for the thrust force (Fz) data	185
5.16	Analysis of variance for quadratic model of thrust force (Fz)	186

5.17	Actual versus predicted values of tool life, volume of material removed, surface roughness, feed force, tangential force and radial force for confirmation run experiment (100 m/min, 0.24 mm/rev)	190
5.18	Actual versus predicted values of tool life, volume of material removed, surface roughness, feed force, tangential force and radial force for confirmation run experiment (170 m/min, 0.16 mm/rev)	190

LIST OF FIGURES

FIGURE NO	TITLE	PAGE
2.1	Some examples of common machining processes (Kalpakjian, 2009)	10
2.2	Metal cutting classification (a) orthogonal cutting (b) oblique cutting (Klocke and Kuchle, 2011)	10
2.3	Orthogonal cutting represents the primary and secondary shear area (Groover, 2010)	11
2.4	Chip configuration in metal cutting process (Klocke and Kuchle, 2011)	12
2.5	Types of chip formation in machining operations (a) discontinuous (b) continuous (c) continuous with built-up edge (d) segmented chip (Kalpakjian, 2009)	12
2.6	Saw-tooth chip formation stages (Poulachon *et al.*, 2001a)	13
2.7	Chip mechanism formation diagram with three cutting velocities (Vc, Vs and V) (Trent and Wright, 2000)	17
2.8	Saw- tooth chip parameters (Vyas and Shaw, 1999)	17
2.9	Sequential stages for conventional and hard turning (Dogra *et al.*, 2010)	19
2.10	Surface integrity: grinding versus turning hardened steel (Sandvik, 2016)	19
2.11	Cost comparison between grinding and finish hard turning (Erdel, 1998)	20

2.12	Cutting tools classification (a) single point tool such as turning process and (b) multi-point tool such as milling process (Groover, 2010)	24
2.13	Cutting tool material toughness versus hardness (Smith, 2008, Davim, 2011)	25
2.14	Tool material hardness against temperature (Davim, 2008)	26
2.15	Cutting speed and feeds ranges for a variety of cutting tool materials (Kalpakjian, 2009)	26
2.16	Terminology for single point cutting tool (Groover, 2010)	31
2.17	Different tool geometry of cutting edge (Özel, 2009)	32
2.18	Wiper (multi-radii) geometry (Davim, 2011)	33
2.19	Categories of water-soluble cutting fluids (El Baradie, 1996a)	35
2.20	Straight cutting oils and their additives (El Baradie, 1996a)	36
2.21	MQL (a) external and (b) internal systems (Ghosh and Rao, 2015)	40
2.22	Sustainability considerations of MQL technique (Skerlos *et al.*, 2008)	41
2.23	Properties of gas vs liquid nitrogen gas phases at 10^5 Pa (Pusavec *et al.*, 2016)	43
2.24	Principle of the vortex tube (Hu *et al.*, 2008)	48
2.25	Schematic view of the vapour-compression refrigeration system	48
2.26	Schematic diagram of the vapour-compression refrigeration system and semiconductor refrigeration system (Su *et al.*, 2007)	49
2.27	Schematic diagram of cold air and MQL system (Inoue and Aoyama, 2004)	50
2.28	Schematic diagram of internal coolant/lubricant for cold air and MQL system (He *et al.*, 2014)	51

2.29	Wear forms in turning tools (ISO3685, 1993)	55
2.30	Flank wear land in turning of microalloyed steel 30MnVS6 at cutting speed of 100 m/min and feed rate of 0.22 mm/rev for 9 min (Ebrahimi and Moshksar, 2009)	57
2.31	Crater Wear	57
2.32	Wear mechanism in metal cutting (Boothroyd, 1988)	58
2.33	Abrasion crater wear on the rake face of the tool at cutting condition Vc = 200 m/min, f = 0.10 mm/rev and d = 0.6 mm (Suresh *et al.*, 2012)	60
2.34	Adhering workpiece material (AISI420) on the tool flank/edge at cutting speed 170 m/min and feed rate 0.28 mm/rev after 1.73 min (Noordin *et al.*, 2007)	61
2.35	Adhesion and abrasion Wear mechanisms (a) workpiece (AISI 4340 stee) with 45 HRC at Vc = 150 m/min, f = 0.2 mm/rev, and d = 0.8 mm (b) workpiece (AISI 4340 steel) with 35 HRC at Vc = 200 m/min, f = 0.2 mm/rev, and d = 0.8 mm (Chinchanikar and Choudhury, 2015)	62
2.36	Attrition and diffusion wear mechanisms when tuning super martensitic stainless steel (S41426) (a) at flank tool face and (b) at rake tool face (Diniz *et al.*, 2016)	63
2.37	Features of wear formulas at the cutting tool through turning process (Klocke and Kuchle, 2011)	64
2.38	Topography features of machined surface (Griffiths, 2001)	67
2.39	Surface roughness feature using arithmetical mean roughness (Ra) (Dawson and Kurfess, 2001a)	67
2.40	White layer formation when turning hardened AISI 5115 steel (Jacobus *et al.*, 2000)	70
2.41	Microstructure alterations of stainless steel at speed = 100m/min, feed = 0.15 mm/re: (a) flank wear land = 0.3 mm) and (b) flank wear land = 0.5 mm (Yan *et al.*, 2012)	70

2.42	Microhardness profile under machined surface (Yazid *et al.*, 2011)	72
2.43	Cutting forces directions in turning process (Özel *et al.*, 2005)	73
2.44	Heat generation zone in metal cutting process (Abukhshim *et al.*, 2006)	75
2.45	Distribution of heat and temperature in workpiece, chip, and tool when the cutting steel materials (Klocke and Kuchle, 2011)	76
2.46	Cutting temperature measurement techniques in metal cutting (Byrne, 1987)	77
2.47	Schematic drawing of workpiece/tool thermocouple technique when turning AISI9310 using coated carbide tool under minimum quantity lubrication (MQL) when (Khan *et al.*, 2009)	78
2.48	Experimental setup of the cutting temperature measurement system using thermocouple technique (Liu *et al.*, 2013)	79
2.49	Schematic diagram of the setup of infrared thermometer (Özek *et al.*, 2006)	80
3.1	Schematic diagram summarizing the first stage of experiments	86
3.2	Schematic diagram summarizing the second stage of experiments	87
3.3	Scan electron micrograph shows the microstructure of martensitic stainless steel (AISI 420) - 48 HRC	90
3.4	Alpha 1350S - CNC lathe machine	91
3.5	PVD-TiAlN coated carbide insert (KC5010 grade - Kennametal)	92
3.6	Left corner tool holder type DCLNR 2020K12	92
3.7	The schematic view of the vapour-compression refrigeration system	93
3.8	Installed copper pipe inside freezer cabinet	94

3.9	Cooling temperature of nitrogen gas vs cooling time	94
3.10	Cold nitrogen gas system (a) experiment setup (b) schematic diagram	95
3.11	Nitrogen and oil mist system (a) machine setup (b) schematic diagram	96
3.12	Cold nitrogen and oil mist system (a) machine setup (b) schematic diagram	97
3.13	Schematic diagram of the air dryer system	99
3.14	Experimental setup of the air dryer system	99
3.15	Optical microscope- Magnification power: 6.5X to 50X (Zeiss, Type Stemi 200-C)	100
3.16	Field emission scanning electron microscope (FESEM) (Zeiss, type: Supra-35VP)-Carl Zeiss	101
3.17	Surface profilometer (E35-B-Accretech Handysurf)	102
3.18	Workpiece samples for microstructure and microhardness	103
3.19	High magnification of optical microscope (Zeiss, Stemi 200-C)	103
3.20	HMV-2T (SHiMADZV) automatic microhardness tester	104
3.21	Kistler dynamometer (Type 9441B) with tool holder	105
3.22	Three channel amplifier and DynoWare software	105
3.23	FILER of infrared camera (E50)	106
3.24	Calibration of emissivity of the infrared camera for cutting tool and workpiece material	107
3.25	Design expert software	109
4.1	Experimental results regarding tool life for different cutting speeds and feed rates under four coolant/lubricant conditions	113
4.2	Flank wear (VB_{max}) of the coated carbide tools (TiAlN) used to machine 48HRC martensitic stainless steel at different cutting speeds and feeds rate under four coolant/lubricant conditions	115

4.3	Crater wear at different cutting speeds and feed rates under four coolant/lubricant conditions	115
4.4	Progression of maximum flank wear face (VB_{max}) depending on the cooling conditions and an image of the cutting tool flank wear (magnification 40x), speed 100 m/min and feed 0.16 mm/rev	116
4.5	Surface roughness at different cutting speed and feed under four coolant/lubricants conditions	118
4.6	Cutting forces under four coolant/lubricant conditions at cutting speed 100 m/min and feed rate 0.16 mm/rev	121
4.7	Cutting forces under four coolant/lubricant conditions at cutting speed 135 m/min and feed rate 0.20 mm/rev	122
4.8	Cutting forces under four coolant/lubricant conditions at cutting speed 170 m/min and feed rate 0.24 mm/rev	123
4.9	Sample measurements of cutting temperature under dry condition at cutting parameters (a) 100 m/min and 0.16 mm/rev (b) 170 m/min and 0.24 mm/rev	124
4.10	Effect of different coolant/lubricants conditions on the maximum chip temperature under at V= 100 m/min and f=0.16 mm/rev	124
4.11	Maximum cutting temperature profile of chip with machining time measurements for turning hardened martensitic stainless steel using TiAlN coated carbide tool under dry condition (new tool)	125
4.12	Maximum chip temperature profile with machining time in turning of hardened martensitic stainless steel (AISI 420) using TiAlN coated carbide tool under cold nitrogen gas with oil mist condition (new tool)	126
4.13	Tool life at various cutting speeds and feeds parameters when turning hardened martensitic stainless steel using TiAlN coated carbide tool	128
4.14	Variation volume of material removed at various cutting speeds and feeds parameters	129

4.15	Progression of flank wear at various cutting speeds and feed rates in relationship to cutting time under cold nitrogen with oil mist condition	130
4.16	Optical microscope images of TiAlN coated carbide tool under cold nitrogen with oil mist condition	132
4.17	SEM images of rake face with EDS analysis for TiAlN coated tool at V = 100 m/min and f = 0.16 mm/rev under dry condition (T_L = 24.0 min)	133
4.18	SEM images of flank face with EDS analysis for TiAlN coated tool at V = 100 m/min and f = 0.16 mm/rev under dry condition (T_L = 24.0 min)	134
4.19	SEM of rake face images with EDX analysis for TiAlN coated tools at V = 100 m/min and f = 0.16 mm/rev under cold nitrogen gas with oil mist condition (T_L = 56.3 min)	135
4.20	SEM of flank face images for TiAlN coated tools at V = 100 m/min and f = 0.16 mm/rev under cold nitrogen gas with oil mist condition with EDX analysis (T_L = 56.3 min)	135
4.21	SEM images of rake face with EDS analysis for TiAlN coated tools at V = 135 m/min and f = 0.20 mm/rev under dry condition (T_L = 5.4 min)	136
4.22	SEM images of rake face with EDX analysis for TiAlN coated tools at V = 135 m/min and f = 0.20 mm/rev under cold nitrogen gas with oil mist condition (T_L = 12.1 min)	136
4.23	SEM images of flank face with EDX analysis for TiAlN coated tools at V = 135 m/min and f = 0.20 mm/rev under dry condition (T_L = 5.4 min)	137
4.24	SEM images of flank face with EDX analysis for TiAlN coated tools at V=135 m/min and f=0.20 mm/rev under cold nitrogen gas with oil mist condition (T_L = 12.1 min)	138

4.25	Surface roughness values at various cutting speeds and feeds parameters when turning hardened martensitic stainless steel using TiAlN coated carbide tool	141
4.26	Surface roughness with progress of machining time at different cutting speeds and feed rates	141
4.27	Microstructure of machined surface of martensitic stainless steel under dry condition at cutting speed of 100 m/min, feed rate of 0.16 mm/rev and depth of cut of 0.20 mm (a) new tool (b) worn tool	142
4.28	Microstructure of machined surface of martensitic stainless steel under cold N_2+MQL condition at cutting speed of 100 m/min, feed rate of 0.16 mm/rev and depth of cut of 0.20 mm (a) new tool (b) worn tool	143
4.29	Influence of the coolant/lubricant conditions and cutting parameters on the microhardness of surface layer for turning hardened stainless steel for new tool	145
4.30	Effect of cutting speed on feed force (Fx) with different feed rates	148
4.31	Effect of cutting speed on tangential force (Fy) with different feed rates	148
4.32	Effect of cutting speed on thrust force (Fz) with different feed rates	149
4.33	Chip morphologies of stainless steel (48 HRC) at various cutting speeds and feed rates using coated carbide under cold nitrogen gas with oil mist condition	150
4.34	Chip morphology under dry condition at (a) cutting speed = 100 m/min and feed = 0.16 mm/rev, (b) cutting speed = 170 m/min and feed = 0.24 mm/rev	153
4.35	Chip morphology under cold nitrogen gas with oil mist condition at (a) cutting speed= 100 m/in and feed= 0.16 mm/rev, (b) cutting speed= 170 m/min and feed= 0.24 mm/rev	154

4.36	Microstructure of cross-sections of chips at cutting speed 100 m/min and feed rate = 0.16 mm/rev under a dry condition for (a) new tool, (b) worn tool and under cold nitrogen with oil condition for (c) new tool and (d) worn tool	156
4.37	Microstructure of cross-sections of chips at cutting speed = 170 m/min and feed rate = 0.24 mm/rev for new tool and worn tool under dry condition for (A) shear band area and (B) machined surface area	157
4.38	Microstructure of cross-sections of chips at cutting speed = 170 m/min and feed rate = 0.24 mm/rev under cold nitrogen gas and oil mist for new tool and worn tool (C) shear band area and (D) machined surface area	158
4.39	Average chip microhardness at different feed rates, cutting speed= 100 m/min and depth of cut= 0.2 mm	159
4.40	Average microhardness distribution at different areas of saw-tooth chip	160
4.41	Variation of (a) peak height and (b) valley height of the saw-tooth chip	161
4.42	Variation of tooth pitch with combinations of cutting speeds and feed rates	162
4.43	Variation of saw-tooth chip angle (Θ_1) with combinations of cutting speeds and feed rates	163
4.44	Variation of crack initiation angle (Θ_2) with combinations of cutting speeds and feed rates	164
4.45	Effects of speed and feed parameters on degree of segmentation	165
4.46	Variation of saw-tooth segmentation frequency with combination of speeds and feed parameters	166
5.1	Perturbation plot for tool life where A and B are cutting speed and feed, respectively	173
5.2	Normal probability plots of residual for (a) tool life (b) volume of material removed	176

5.3	Plot of residuals vs predicted for (a) tool life (b) volume of material removed	176
5.4	Contours surface graphs of (a) tool life (b) volume material removal rate(VMR)	177
5.5	3D Response surface graphs of (a) tool life (b) volume of material removed (VMR)	177
5.6	Surface roughness (a) normal probability plots residuals (b)residuals vs predicted	181
5.7	Contours surface graphs of roughness	181
5.8	Response surface graphs of 3D surface for surface roughness	182
5.9	Normal probability plots of residual for (a) Fx,(b) Fy (c) Fz	188
5.10	Plot of residuals vs predicted for (a) Fx (b) Fy (c) Fz	188
5.11	Contours surface graphs of (a) Fx (b) Fy (c) Fz	189
5.12	3D Response surface graphs of (a) Fx (b) Fy (c) Fz	189
5.13	Desirability plot of the cutting parameters to achieve the maximum tool life and material removal rate and minimum surface roughness and cutting forces	192

LIST OF ABBREVIATIONS

CMQL	-	Cold minimum quantity lubricant
CN_2	-	Cold nitrogen gas
CN_2+ MQL	-	Cold nitrogen gas with oil mist
CO_2	-	Carbon dioxide
d	-	Depth of cut (mm)
D_{seg}	-	Degree of segmentation
f	-	Feed (mm/rev)
F_F	-	Friction force sideways to tool rake face (N)
Fn	-	Force normal to shear plane (N)
F_N	-	Force normal to tool rake face (N)
Fs	-	Shear force parallel to shear plane (N)
f_{seg}	-	Saw-tooth segmentation frequency (N)
Fx	-	Feed force (N)
Fy	-	Tangential force (N)
Fz	-	Thrust force (N)
h_{max}	-	Chip peak height.(µm)
h_{min}	-	Chip valley height (µm)
HRC	-	Rockwell C hardness
MQL	-	Minimum quantity lubrication
MRR	-	Material removal rate (cm^3/min)
N_2 + MQL	-	Nitrogen gas with oil mist
P_{seg}	-	Chip tooth pitch (µm)
PVC	-	Physical vapour deposition
r	-	Chip thickness ratio
Ra	-	Arithmetical mean roughness (µm)

r_{seg}	-	Saw-tooth chip segmentation ratio
t_1	-	Undeformed chip thickness (μm)
t_2	-	Deformed chip thickness (μm)
TiAlN	-	Titanium aluminum nitride
T_L	-	Tool life (min)
V	-	Cutting speed (m/min)
VB	-	Width of flank wear land
Vc	-	Chip velocity
Vs	-	Shearing velocity
x_1, x_2	-	Input variable (machining factors)
y_{est}	-	Estimated variable (machining response)
α	-	Rake angle
β	-	Friction angle
θ_1	-	Saw-tooth chip angle
θ_2	-	Crack initiation angle
μ	-	Coefficient of friction
φ	-	Shear angle

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Workpiece Certificate	218
B	ISO Designation System for Tool Holder for External Turning	219
C	ISO Code for Insert	220
D	Chip Thickness and Saw-Tooth Chip Measurements	222
E	Chip Microhardness Indenters	223
F	List of Related Publications	224

CHAPTER 1

INTRODUCTION

1.1 Overview

Automotive and the mould and die are significant industries in the manufacturing sector. Stainless steel alloys such as martensitic stainless steel are widely used in the mould and die industry due to their high strength, good corrosion and wear resistance, more stable in hardening and good surface finish. These properties are beneficial in producing consistent products over an expensive running period with less maintenance and operable in harsh environment. One of its applications is as plastic mould. Various plastic and thermoset plastic products can be produced using hardened stainless steel moulds with hardness of 45 - 50 HRC.

Hard turning is machining process for materials with a hardness value of 45 HRC and above. This process has become an alternative to grinding because of its flexibility, economic and ecological aspects. Machining time has reduced as high as 60% compare to conventional turning. Longer tool life, better surface quality and high accuracy can be achieved with small value of depth of cut and feed rate when using hard turning (Huddle, 2001, Tönshoff et al., 2000, König et al., 1990, Benga and Abrao, 2003).

Generally, hard turning is conducted using advanced cutting tools such as ceramic, cubic boron nitride (CBN), and PCBN tools. In order to improve the hardness and surface conditions of carbide tools, hard coating materials such as titanium carbide (TiC), titanium nitrate (TiN), alumina (Al_2O_3), titanium aluminium nitride (TiAlN) and titanium carbonitride (TiCN) are applied. Carbide tools proven to lower the manufacturing cost compared to ceramic, cubic boron nitride (CBN) and PCBN tools (Kang *et al*., 2008). Noordin *et al.* (2007) had successfully used coated carbide tool when turning hardened stainless steel under dry condition.

Optimization of the machining parameters can decrease the total costs by increasing the productivity without affecting the loss of tool life. High cutting temperature has undesirable effect on the cutting tool and product quality. This is because decreasing in tool life can affect dimensional deviation of the machine parts, and thus damage the surface integrity.

Effective cooling methods can significantly contribute to tool life improvement by minimizing the friction and decreasing the cutting temperature. Therefore, it is essential to use cutting fluids in metal cutting to decrease the high temperature in the cutting area particularly on hard materials. Cutting fluids have been used extensively in different machining processes for their capability to prolong tool life and improve machined surface quality. Nevertheless, cutting fluids in metal cutting processes possess many health issues for machine operators and environmental contamination, predominantly in regard to their disintegration and final discarding.

In order to eliminate or to reduce these issues, several studies have been carried out using green machining techniques. Thus to serve that purpose, new dry and near-dry machining approaches have been used such as; dry cutting, minimum quantity lubricant (MQL), cryogenic cooling, gas-based cooling, and cryogenic with minimum quantity lubricant (CMQL) .

Dry cutting is one approach in sustainable and green machining. However, in dry machining high temperature is generated at the interface of tool-chip and tool-workpiece surfaces incorporated with plastic deformation. This gives rise to decreased tool life, affects surface finish and prompts deep white layer and compressive residual stress in the subsurface of the component surface (Guo and Sahni, 2004).

Another green machining approach is a gas-based cooling. Gasses as cooling/lubrications were adopted to reduce cutting fluids application in machining processes and enhance the machinability through the changes in cutting tool/workpiece material properties.

Main gasses commonly used as coolant are air, N_2, Ar, He and CO_2, and they might be used in combination with vegetable oils in the forms of mist or droplets to improve their lubrication aptitude. Compressed gas based coolant has more advantages when conventional cooling techniques fail to penetrate the chip-tool interface, as well as avoiding oxidation of the workpiece and the chips.

Developments for a new gas coolant with MQL system create growth towards the objectives of sustainable manufacturing. This eliminates the most significant health and water pollution hazards related to conventional metal cutting fluids. MQL technique involves a very low amount of oil (less than 50 mL/h) incorporated with pressurized air at the cutting area. The spray mode can be used by sprayed oil from external supply device through one or more nozzles, or via internal holes fabricated inside the cutting tools.

Many researchers have used the MQL technique in machining processes such as turning and milling processes. Furthermore, cryogenic coolant with oil mist lubricant is used in difficult-to-cut materials in order to compensate for the coolant effects in MQL technique.

1.2 Problem Statement

Inefficient heat removal from the cutting zone when cutting stainless steel material leads to the weakness of the cutting tip. In addition, the stainless steel material has a tendency to adhere on the tool surface and causes work hardening. These issues decrease tool life and affect the surface integrity such as increasing the depth of the plastically deformed sub-layer and residual stress distribution, resulting in increasing machining cost and affecting the service performance of the manufactured components.

Conventional cutting fluid reduces the heat created during cutting, thus increase the tool life and enhance the surface finish. However, the cutting fluids do not easily penetrate the tool–workpiece and tool–chip interfaces which are under seizure condition when it is evaporated by high temperature produced at the tool edge (Shaw, 2005). Furthermore, the use of conventional cutting fluids in the industry can result in health and environmental issues, especially in their degradation and problematic final discarding (El Baradie, 1996b).

On the other hand, the health hazards and environmental pollution related with the usage of these fluids together with the developing governmental rules have resulted in increasing machining costs (Shokrani *et al.*, 2012, El Baradie, 1996a). For the manufacture of automobiles in the European countries, the cost of applying conventional fluids is around 20% of the whole machining cost (Brockhoff and Walter, 1998).

Dry cutting has proved as a sustainable machining approach. However, generation of high temperature at the cutting area can lead to decreasing tool life and surface quality (Guo and Sahni, 2004). Therefore, different cooling strategies have been improved (developed) in order to reduce the cutting temperature.

The MQL technique consists of using a combination of a very little quantity of cutting oil (6–100 mL/h) and compressed air jet, directed to the cutting area. MQL in metal cutting eliminates the heat produced through machining. This is accomplished mostly by the convection of compressed air and partly by evaporation of cutting oil. However, MQL acts as a lubricant rather than coolant in metal cutting. Thus, MQL will not perform well in the machining processes where many thermal issues are involved such as machining of difficult-to-cut materials (Ezugwu, 2005, Attanasio *et al.*, 2006, Obikawa *et al.*, 2006). Therefore oil mist in combination with gas coolant may be considered as an alternative solution to overcome dry cutting and MQL issues.

In metal cutting, compressed gas coolant is appropriate when conventional cutting fluids cannot penetrate the chip-tool interface. Vegetable oils in MQL technique are readily biodegradable, even when combined with gasses (coolant) such as nitrogen.

Nitrogen is an inert gas. It forms 78% of the atmosphere and is lighter than air (Shokrani *et al.*, 2012). The latest and most recent research in using nitrogen gas combined with MQL was done by Shizuka *et al.*, (2009). As far as these are concerned, exploration in using component of gasses or cold gasses with MQL may improve the machining cost for related industries.

Until now there are little researchs involving the use of cold gasses combined with MQL. Therefore it remains a largely unexplored practice either to apply gasses or cold gasses with MQL techniques among industrial users. In addition, knowledge on the tool wear mechanisms, surface integrity, and cutting temperature when hard turning stainless steel using cold nitrogen gas with oil mist coolant/lubricant technique are still lacking.

1.3 Objectives

The objectives of this study are as follows:

i. To study the performances of cold nitrogen, nitrogen gas with oil mist and cold nitrogen gas with oil mist conditions in terms of tool life, surface roughness and machining forces, while using dry cutting as benchmark when turning hardened martensitic stainless steel (AISI420) using physical vapour deposition (PVD) titanium aluminum nitride (TiAlN) coated carbide cutting tool (KC 5010) for different cutting parameters

ii. To investigate the wear mechanisms, the quality of the machined surface and chips generated when hard turning of martensitic stainless steel under cold nitrogen gas with oil mist condition.

iii. To develop mathematical models for machining responses (tool life, the volume of material removed, surface roughness and cutting forces) for optimum coolant/lubricant conditions and define their relationship with the parameters studied (cutting speed and feed rate).

iv. To optimize the cutting parameters in turning hardened martensitic stainless steel in order to achieve better machining responses.

1.4 Scope of Study

This study is set within the following scopes:

i. Experiments were conducted under dry, cold N_2, N_2 + MQL and cold N_2 + MQL coolant/lubricant conditions.

ii. The workpiece material was hardened martensitic stainless steel (48 HRC) and the cutting tool was fine grained WC-6 wt % Co substrate and coated with PVD-TiAlN.

iii. Experiments were conducted at different cutting speeds (100, 135, and 170 m/min) and feed rates (0.16, 0.20, and 0.24 mm/rev) while the depth of cut was kept constant (0.2 mm).

iv. Investigation of cold nitrogen gas with oil mist as coolant and lubricant.

1.5 Organization of Thesis

This thesis contents six chapters. Chapter 1 presents on general overview of the research. Chapter 2 covers on the literature of the relevant research study in these areas. It covers: stainless steel, hard turning, cutting tool, conventional cooling and environmentally friendly machining techniques as well as tool wear, wear mechanism, surface integrity cutting forces and chip morphology. Chapter 3 describes the experimental setup for the cold nitrogen system, nitrogen gas and oil mist system, cold nitrogen gas and oil mist system, stainless steel material, coated carbide tools and measurement tools. Chapter 4 covers the comparison study between dry, cold nitrogen gas, nitrogen gas and oil mist, cold nitrogen gas and oil mist conditions. In this chapter, the effect of cutting speed and feed rate on tool life, surface roughness and cutting forces were investigated. In addition, this study included the examination on the sub-surface deformation and microhardness as well as chip formation characteristics. In Chapter 5, the development of models for tool life, volume of material removed, surface roughness and cutting forces data using design expert software were developed for the optimization of cutting parameters. Finally, Chapter 6 concludes of the present study and offers some suggestions for possible future research.

1.6 Significant of This Study

This research contributes in studying the effect of nitrogen gas (ambient and cold temperature) with oil mist conditions on machining responses such as tool life, the volume of material removed, surface roughness, cutting forces, wear mechanism and chip morphology during the turning hardened martensitic stainless steel using coated carbide cutting tool. It was expected that results from this study will show that cold nitrogen gas and oil mist condition will provide an improvement in machining responses compared to dry machining.

It is also expected that cold nitrogen gas with oil mist condition performance will improve surface integrity, enhance environmental friendliness, reduce cost, provide good geometrical accuracy of the machined parts, and eliminates grinding process in the manufacturing industries particularly those involved in the machining of hardened materials such as in the mould and die industries. Last but not least, cold nitrogen gas with oil mist condition is predicted to be useful towards achieving sustainable and green machining and thus provides an alternative to conventional cutting fluids in machining processes.

REFERENCES

Abdalla, H., Baines, W., Mcintyre, G. & Slade, C. (2007). Development of Novel Sustainable Neat-Oil Metal Working Fluids for Stainless Steel and Titanium Alloy Machining. Part 1. Formulation Development. *The International Journal of Advanced Manufacturing Technology*. 34(1-2), 21-33.

Abrão, A. M., Aspinwall, D. K. & Wise, M. L. (1995). Tool Life and Workpiece Surface Integrity Evaluations when Machining Hardened AISI H13 and AISI E52100 Steels with Conventional Ceramic and PCBN Tool Materials. *Technical Papers-Society of Manufacturing Engineers-All Series*.

Abrão, A. M., Ribeiro, J. L. S. & Davim, J. P. (2011). Surface Integrity. *Machining of Hard Materials.* Springer.

Abukhshim, N., Mativenga, P. & Sheikh, M. (2006). Heat Generation and Temperature Prediction in Metal Cutting: A Review and Implications for High Speed Machining. *International Journal of Machine Tools and Manufacture*. 46(7), 782-800.

Adler, D., Hii, W.-S., Michalek, D. & Sutherland, J. (2006). Examining the Role of Cutting Fluids in Machining and Efforts to Address Associated Environmental/Health Concerns. *Machining Science and Technology.* 10(1), 23-58.

Altan, E., Kiyak, M. & Cakir, O. (2002). The Effect of Oxygen Gas Application into Cutting Zone on Machining. Proceedings of Sixth Biennial Conference on Engineering System Design and Analysis (ESDA2002). Istanbul. 1-5.

Anthony, X. (2015). Analysis of Cutting Force and Chip Morphology During Hard Turning of AISI D2 Steel. *Journal of Engineering Science and Technolog.* 10(3), 282-290.

Aouici, H., Yallese, M. A., Chaoui, K., Mabrouki, T. & Rigal, J.-F. (2012). Analysis of Surface Roughness and Cutting Force Components in Hard Turning with CBN Tool: Prediction Model and Cutting Conditions Optimization. *Measurement.* 45 (3), 344-353.

Arrazola, P. & Ozel, T. (2008). Numerical Modelling of 3D Hard Turning using Arbitrary Lagrangian Eulerian Finite Element Method. *International Journal of Machining and Machinability of Materials.* 4(1), 14-25.

Astakhov, V. P. (2006). *Tribology of Metal Cutting*, Elsevier.

Attanasio, A., Gelfi, M., Giardini, C. & Remino, C. (2006). Minimal Quantity Lubrication in Turning: Effect on Tool Wear. *Wear.* 260(3)**,** 333-338.

Barry, J. & Byrne, G. (2002a). Chip formation, Acoustic Emission and Surface White Layers in Hard Machining. *CIRP Annals-Manufacturing Technology.* 51(1), 65-70.

Barry, J. & Byrne, G. (2002b). The Mechanisms of Chip Formation in Machining Hardened Steels. *Journal of Manufacturing Science and Engineering.* 124(3), 528-535.

Bartarya, G. & Choudhury, S. (2012). State of the Art in Hard Turning. *International Journal of Machine Tools and Manufacture.* 53(1), 1-14.

Bayoumi, A. & Xie, J. (1995a). Some Metallurgical Aspects of Chip Formation in Cutting Ti-6wt.% Al-4wt.% V alloy. *Materials Science and Engineering: A.* 190(1), 173-180.

Bayoumi, A. & Xie, J. (1995b). Some metallurgical aspects of chip formation in cutting Ti-6wt.% Al-4wt.% V alloy. *Materials Science and Engineering: A,* 190, 173-180.

Becze, C. & Elbestawi, M. (2002). A Chip Formation Based Analytic Force Model for Oblique Cutting. *International Journal of Machine Tools and Manufacture.* 42(4), 529-538.

Benga, G. C. & Abrao, A. M. (2003). Turning of Hardened 100Cr6 Bearing Steel with Ceramic and PCBN Cutting Tools. *Journal of Materials Processing Technology.* 143, 237-241.

Bermingham, M., Kirsch, J., Sun, S., Palanisamy, S. & Dargusch, M. (2011). New Observations on Tool Life, Cutting Forces and Chip Morphology in Cryogenic Machining Ti-6Al-4V. *International Journal of Machine Tools and Manufacture.* 51(6), 500-511.

Boothroyd, G. (1988). *Fundamentals of Metal Machining and Machine Tools*, CRC Press.

Bramfitt, B. L. & Benscoter, A. O. (2001). *Metallographer's Guide: Practice and Procedures for Irons and Steels*, ASM International.

Brinksmeier, E., Schneider, E., Theiner, W. & Tönshoff, H. (1984). Nondestructive Testing for Evaluating Surface Integrity. *CIRP Annals-Manufacturing Technology*. 33(2), 489-509.

Brockhoff, T. & Walter, A. (1998). Fluid Minimization in Cutting and Grinding. *Abrasives, Journal of Abrasives Engineering Society*. 10(11), 38-42.

Brown, R. (1981). On the Mechanics of Chip Segmentation in Machining. *Journal of Engineering for Industry*. 103(1), 33-51.

Bruni, C., Forcellese, A., Gabrielli, F. & Simoncini, M. (2006). Effect of the Lubrication-Cooling Technique, Insert Technology and Machine Bed Material on the Workpart Surface Finish and Tool wear in Finish Turning of AISI 420B. *International Journal of Machine Tools and Manufacture*. 46(12), 1547-1554.

Byrne, G. (1987). Thermoelectric Signal Characteristics and Average Interfacial Temperatures in the Machining of Metals under Geometrically Defined Conditions. *International Journal of Machine Tools and Manufacture*. 27(2), 215-224.

Çakır, O., Kıyak, M. & Altan, E. (2004). Comparison of Gases Applications to Wet and Dry Cuttings in Turning. *Journal of Materials Processing Technology,* 153, 35-41.

Čep, R., Neslušan, M. & Barišić, B. 2008. Chip Formation Analysis during Hard Turning. *Strojarstvo: časopis za teoriju i praksu u strojarstvu*. 50, 337-346.

Che-Haron, C. & Jawaid, A. 2005. The effect of Machining on Surface Integrity of Titanium Alloy Ti–6% Al–4% V. *Journal of Materials Processing Technology*. 166(2), 188-192.

Chinchanikar, S. & Choudhury, S. (2013). Investigations on Machinability Aspects of Hardened AISI 4340 Steel at Different Levels of Hardness using Coated Carbide Tools. *International Journal of Refractory Metals and Hard Materials*. 38, 124-133.

Chinchanikar, S. & Choudhury, S. (2015). Predictive Modeling for Flank Wear Progression of Coated Carbide Tool in Turning Hardened Steel under

Practical Machining Conditions. *The International Journal of Advanced Manufacturing Technology*. 76(5-8), 1185-1201.

Conceição, M. M., Candeia, R. A., Silva, F. C., Bezerra, A. F., Fernandes, V. J. & Souza, A. G. (2007). Thermoanalytical Characterization of Castor Oil Biodiesel. *Renewable and Sustainable Energy Reviews.* 11(5)**,** 964-975.

Davies, M., Chou, Y. & Evans, C. (1996a). On Chip Morphology, Tool Wear and Cutting Mechanics in Finish Hard Turning. *CIRP Annals-Manufacturing Technology*. 45(1), 77-82.

Davies, M., Ueda, T., M'saoubi, R., Mullany, B. & Cooke, A. (2007). On the Measurement of Temperature in Material Removal Processes. *CIRP Annals-Manufacturing Technology.* 56(2), 581-604.

Davies, M. A., Chou, Y. & Evans, C. J. (1996b). On Chip Morphology, Tool Wear and Cutting Mechanics in Finish Hard Turning. *CIRP Annals-Manufacturing Technology*. 45(1), 77-82.

Davim, J. P. (2008). *Machining: Fundamentals and Recent Advances*, Springer Science & Business Media.

Davim, J. P. (2011). *Machining of Hard Materials*, Springer Science & Business Media.

Davim, J. P. & Figueira, L. (2007). Comparative Evaluation of Conventional and Wiper Ceramic Tools on Cutting Forces, Surface Roughness, and tool wear in hard turning AISI D2 steel. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*. 221(4)**,** 625-633.

Dawson, T. G. & Kurfess, T. R. (2001a). Hard turning, Tool Life, and Surface Quality. *Manufacturing Engineering(USA).* 126(4), 88.

Dawson, T. G. & Kurfess, T. R. (2001b). Tool Life, Wear Rates, and Surface Quality in Hard Turning. *Transactions-north American Manufacturing Research Institution of SME*. 175-182.

De Lima, J., De Avila, R. & Abrao, A. (2007). Turning of Hardened AISI 4340 Steel using Coated Carbide Inserts. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*. 221(8), 1359-1366.

De Melo, A. C., Milan, J. C. G., Silva, M. B. D. & Machado, Á. R. (2006). Some Observations on Wear and Damages in Cemented Carbide Tools. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*. 28(3), 269-277.

Devillez, A., Lesko, S. & Mozer, W. (2004). Cutting Tool Crater Wear Measurement with White Light Interferometry. *Wear.* 256(1), 56-65.

Dhar, N. & Kamruzzaman, M. (2007). Cutting Temperature, Tool Wear, Surface Roughness and Dimensional Deviation in Turning AISI-4037 Steel under Cryogenic Condition. *International Journal of Machine Tools and Manufacture.* 47(5), 754-759.

Diniz, A. E., Machado, Á. R. & Corrêa, J. G. (2016). Tool wear Mechanisms in the Machining of Steels and Stainless Steels. *The International Journal of Advanced Manufacturing Technology*. 1-12.

Dixit, U. S., Sarma, D. & Davim, J. P. (2012). *Environmentally Friendly Machining*, Springer Science & Business Media.

Dogra, M., Sharma, V. S., Sachdeva, A., Suri, N. M. & Dureja, J. S. (2010). Tool Wear, Chip Formation and Workpiece Surface Issues in CBN Hard Turning: A review. *International Journal of Precision Engineering and Manufacturing.* 11(2), 341-358.

Dolinšek, S., Ekinović, S. and Kopač, J. (2004). A Contribution to the Understanding of Chip Formation Mechanism in High-speed Cutting of Hardened Steel. *Journal of Materials Processing Technology.* 157, 485-490

Dubec, J., Neslusan, M., Micietova, A. & Cillikova, M. (2013). Influence of Flank Wear on Decomposition of Cutting Forces in Turning. *MM Science Journal*. 448-451.

Dudzinski, D., Devillez, A., Moufki, A., Larrouquere, D., Zerrouki, V. and Vigneau, J. (2004). A review of Developments Towards Dry and High Speed Machining of Inconel 718 Alloy. *International Journal of Machine Tools and Manufacture.* 44(4), 439-456.

Ebrahimi, A. & Moshksar, M. (2009). Evaluation of Machinability in Turning of Microalloyed and Quenched-Tempered Steels: Tool wear, Statistical Analysis, Chip Morphology. *Journal of Materials Processing Technology.* 209(2), 910-921.

Ekinovic, S., Dolinsek, S. and Jawahir, I. (2004). Some Observations of the Chip Formation Process and the White Layer Formation in High Speed Milling of Hardened Steel. *Machining Science and Technology.* 8(2), 327-340.

El-hossainy, T. (2010). Effect of Gas Cutting Fluids on Machinability of Different Materials. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture.* 224(7), 1057-1068.

El baradie, M. (1996a). Cutting Fluids: Part I. Characterisation. *Journal of Materials Processing Technology.* 56(1), 786-797.

El baradie, M. (1996b). Cutting Fluids: Part II. Recycling and Clean Machining. *Journal of Materials Processing Technology.* 56(1), 798-806.

Elmunafi, M. H. S. (2016). *Performance Evaluation of Finish Hard Turning using Coated Carbide Cutting Tools under Minimum Quantity Lubrication.* PhD thesis, Universiti Teknologi Malaysia.

Elmunafi, M. H. S., Yusof, N. M. and Kurniawan, D. (2015(. Effect of Cutting Speed and Feed in Turning Hardened Stainless Steel using Coated Carbide Cutting Tool under Minimum Quantity Lubrication using Castor Oil. *Advances in Mechanical Engineering.* 7(8), 1687814015600666.

Erdel, B. P. (1998). *New Dimensions in Manufacturing*, Hanser Gardner Publications.

Ezugwu, E. (2005). Key Improvements in the Machining of Difficult-to-cut Aerospace Superalloys. *International Journal of Machine Tools and Manufacture.* 45(12), 1353-1367.

Ezugwu, E. & Okeke, C. (2002). Behavior of Coated Carbide Tools in High Speed Machining of a Nickel Base Alloy. *Tribology Transactions.* 45(1)**,** 122-126.

Ezugwu, E. and Olajire, K. (2002). Evaluation of Machining Performance of Martensitic Stainless Steel (JETHETE). *Tribology Letters.* 12(3), 183-187.

Garcia Navas, V., Ferreres, I., Maranon, J. A., Garcia-Rosales, C. and Sevillano, J. G. (2008). White Layers Generated in AISI O1 Tool Steel by Hard Turning or by EDM. *International Journal of Machining and Machinability of Materials.* 4(4), 287-301.

Ghani, J. A., Haron, C. H. C., Kasim, M. S., Sulaiman, M. A. & Tomadi, S. H. (2015). Wear Mechanism of Coated and Uncoated Carbide Cutting Tool in Machining Process. *Journal of Materials Research*. 1-7.

Ghosh, A. & Mallik, A. K. (1986). *Manufacturing Science*. Ellis Horwood.

Ghosh, S. & Rao, P. V. (2015). Application of Sustainable Techniques in Metal Cutting for Enhanced Machinability: A review. *Journal of Cleaner Production*. 100, 17-34.

Ginting, Y. R., Boswell, B., Biswas, W. K. & Islam, M. N. (2016). Environmental Generation of Cold Air for Machining. *Procedia CIRP.* 40, 648-652.

Giunta, A. A. (1997). *Aircraft Multidisciplinary Design Optimization using Design of Experiments Theory and Response Surface Modeling Methods.* PhD Thesis, Virginia Polytechnic Institute and State University, Virginia.

Griffiths, B. (2001). *Manufacturing Surface Technology: Surface Integrity and Functional Performance*. Elsevier.

Grochalski, K. and Jabłoński, P. (2016). Temperature Measurements of Turning with WCCo-cBN Composite Cutting Tools Thermographic and Contact Methods. *Methods and Models in Automation and Robotics (MMAR). 2016. 21st International Conference* IEEE, 284-287.

Groover, M. P. (2010). *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*. John Wiley & Sons.

Guo, Y. and Sahni, J. (2004). A comparative Study of Hard Turned and Cylindrically Ground White Layers. *International Journal of Machine Tools and Manufacture.* 44(2), 135-145.

Hamdan, A., Sarhan, A. A. and Hamdi, M. (2012). An Optimization Method of the Machining Parameters in High-Speed Machining of Stainless Steel using Coated Carbide Tool for Best Surface Finish. *The International Journal of Advanced Manufacturing Technology*. 58(1-4), 81-91.

He, A.D., Ye, B.Y. and Wang, Z.Y. (2014). Experimental Effect of Cryogenic MQL Cutting 304 Stainless Steel. *In Key Engineering Materials*. 621, 3-8. Trans Tech Publications.

He, J. and Ren, G. S. (2011). CNC Cutting Performance in Processing Using Cool-Air Cutting Technology. *Advanced Materials Research.* 154, 973-976.

He, N., Li, L. and Li, X. (2004). A New Cooling Nitrogen Gas Generator and Experiments of High Speed Milling of Ti alloy. *Materials Science Forum. Trans Tech Publ.* 471, 140-143.

Hong, S. Y. (2001). Economical and Ecological Cryogenic Machining. *Journal of Manufacturing Science and Engineering.* 123(2), 331-338.

Hong, S. Y., Ding, Y. and Jeong, W.-C. (2001). Friction and Cutting Forces in Cryogenic Machining of Ti–6Al–4V. *International Journal of Machine Tools and Manufacture.* 41(15), 2271-2285.

Hu, J. & Chou, Y. K. (2007). Characterizations of Cutting Tool Flank Wear-Land Contact. *Wear*. 263(7), 1454-1458.

Hu, J. S., Liu, D. X., Liu, Y. Z., YuE, C. X. and Liu, X. L. (2008). Experimental Investigation on Air Cooling of GCr15. *Key Engineering Materials.* 375, 197-200.

Huddle, D. (2001). New Hard Turning Tools and Techniques Offer a Cost-Effective Alternative to Grinding. *Tooling and Production Magazine.* 80, 96-103.

Inoue, S. and Aoyama, T. (2004). Application of Air Cooling Technology and Minimum Quantity Lubrication to Relief Grinding of Cutting Tools. *In Key Engineering Materials*. 257, 345-352. Trans Tech Publications.

International Organization for Standardization. (1993). *Tool-Life Testing with Single Point Turning Tools*. ISO3685.

Jacobus, K., Devor, R. and Kapoor, S. (2000). Machining-Induced Residual Stress: Experimentation and Modeling. *Journal of Manufacturing Science and Engineering,* 122, 20-31.

Jindal, P., Santhanam, A., Schleinkofer, U. and Shuster, A. (1999). Performance of PVD TiN, TiCN, and TiAlN Coated Cemented Carbide tools in Turning. *International Journal of Refractory Metals and Hard Material*s, 17(1), 163-170.

J Joseph, P., Saxena, D. and Sharma, D. (2007). Study of Some Non-edible Vegetable Oils of Indian Origin for Lubricant Application. *Journal of Synthetic Lubrication.* 24(4), 181-197.

Kalpakjian, S. A. S., S. R (2009). *Manufacturing Engineering and Technology,* New Jersey, Prentice Hall.

Kamruzzaman, M. and Dhar, N. (2008). The effect of Applying High-Pressure Coolant (HPC) Jet in Machining of 42CrMo4 Steel by Uncoated Carbide Inserts. *Journal of Mechanical Engineering.* 39(2), 71-77.

Kang, M.C., Kim, K.H., Shin, S.H., Jang, S.H., Park, J.H. and Kim, C. (2008). Effect of the Minimum Quantity Lubrication in High-Speed End-Milling of AISI D2 Cold-Worked Die Steel (62 HRC) by Coated Carbide Tools. *Surface and Coatings Technology*. *202*(22), 5621-5624.

Kaynak, Y., Karaca, H. and Jawahir, I. (2011). Cryogenic Machining of NiTi Shape Memory Alloy. *6th International Conference and Exhibition on Design and Production of Machines and Dies/Molds*. 23-26.

Kaynak, Y., Lu, T. and Jawahir, I. (2014). Cryogenic Machining-Induced Surface Integrity: a Review and Comparison with Dry, MQL, and Flood-Cooled machining. *Machining Science and Technology.* 18(2), 149-198.

Khan, A. A. and Ahmed, M. I. (2008). Improving Tool Life using Cryogenic Cooling. *Journal of Materials Processing Technology.* 196(1), 149-154.

Khan, M. and Dhar, N. (2006). Performance Evaluation of Minimum Quantity Lubrication by Vegetable Oil in Terms of Cutting Force, Cutting Zone Temperature, Tool Wear, Job Dimension and Surface Finish in Turning AISI-1060 steel. *Journal of Zhejiang University-SCIENCE A.* 7(11), 1790-1799.

Khan, M., Mithu, M. and Dhar, N. (2009). Effects of Minimum Quantity Lubrication on Turning AISI 9310 Alloy Steel Using Vegetable Oil-Based Cutting Fluid. *Journal of Materials Processing Technology.* 209(15), 5573-5583.

Khorram, A., Rezaeian, M. and Bakhtiari-Nejad, F. (2013). Multiple Cracks Detection in a Beam Subjected to a Moving Load using Wavelet Analysis Combined with Factorial Design. *European Journal of Mechanics-A/Solids.* 40, 97-113.

Khrais, S.K. and Lin, Y.J. (2007). Wear Mechanisms and Tool Performance of TiAlN PVD Coated Inserts During Machining of AISI 4140 Steel. *Wear.* 262(1), 64-69.

Kishawy, H. E. A. (1998). *Chip Formation and Surface Integrity in High Speed Machining of Hardened Steel.* Ph.D. Thesis. McMaster University, Ontario.

Klocke, F. and Eisenblätter, G. (1997). Dry cutting. *CIRP Annals-Manufacturing Technology.* 46(2), 519-526.

Klocke, F. and Kuchle, A. (2011). *Manufacturing Processes. 1-Cutting.* RWTH Edition. Springer-Verlag Berlin Heidelberg.

Ko, T. J., Kim, H. S. & Chung, B. G. (1999). Air–Oil Cooling Method for Turning of Hardened Material. *The International Journal of Advanced Manufacturing Technology.* 15(7), 470-477.

Koenig, W. and Boemcke, A. (1989). Wear Mechanisms of Ultra-hard Non-metallic Cutting Materials. *Fresenius' Zeitschrift für Analytische Chemie.* 333(4-5), 461-465.

Komanduri, R. and Brown, R. (1981). On the Mechanics of Chip Segmentation in Machining. *Journal of Engineering for Industry.* 103(1), 33-51.

König, W., Klinger, M. & Link, R. (1990). Machining Hard Materials with Geometrically Defined Cutting Edges—Field of Applications and Limitations. *CIRP Annals-Manufacturing Technology*. 39(1), 61-64.

König, W., Komanduri, R., Toenshoff, H. & Ackershott, G. 1984. Machining of Hard Materials. *CIRP Annals-Manufacturing Technology,* 33, 417-427.

Kose, E., Kurt, A. and Seker, U. (2008). The Effects of the Feed Rate on the Cutting Tool Stresses in Machining of Inconel 718. *Journal of Materials Processing Technology*. 196(1), 165-173.

Krolczyk, G., Legutko, S. and Gajek, M. (2013). Predicting the Surface Roughness in the Dry Machining of Duplex Stainless Steel (DSS). *Metalurgija*. 52(2), 259-262.

Krolczyk, G., Nieslony, P. and Legutko, S. (2014). Microhardness and Surface Integrity in Turning Process of Duplex Stainless Steel (DSS) for Different Cutting Conditions. *Journal of Materials Engineering and Performance. 23(3), 859-866.*

Kumar, C. R. V., and Ramamoorthy, B. (2007). Performance of Coated Tools During Hard Turning Under Minimum Fluid Application. *Journal of Materials Processing Technology*. 185(1), 210-216.

Kumar, K. K. and Choudhury, S. (2008). Investigation of Tool Wear and Cutting Force in Cryogenic Machining Using Design of Experiments. *Journal of Materials Processing Technology*. 203(1), 95-101.

Kumar, K. S. and Senthilkumaar, J. (2013). Analysis of Flank Wear and Chip Morphology when Machining Super Duplex Stainless Steel in a Gas Cooled Environment. *International Journal of Engineering and Technology*.

Kuram, E., Ozcelik, B. and Demirbas, E. (2013). Environmentally Friendly Machining: Vegetable Based Cutting Fluids. *Green Manufacturing Processes and Systems*. Springer.

Kurniawan, D., Yusof, N. M. and Sharif, S. (2010). Hard Machining of Stainless Steel Using Wiper Coated Carbide: Tool Life and Surface Integrity. *Materials and Manufacturing Processes*. 25(6), 370-377.

Lalwani, D., Mehta, N. & Jain, P. (2008). Experimental Investigations of cutting Parameters Influence on Cutting Forces and Surface Roughness in Finish Hard Turning of MDN250 Steel. *Journal of materials processing technology*. 206(1), 167-179.

Liao, Y., Lin, H. and Chen, Y. (2007). Feasibility Study of the Minimum Quantity Lubrication in High-Speed End Milling of NAK80 Hardened Steel by Coated Carbide Tool. *International Journal of Machine Tools and Manufacture.* 47(11), 1667-1676.

Liew, W. Y. H. and Ding, X. (2008). Wear Progression of Carbide Tool in Low-Speed End Milling of Stainless Steel. *Wear,* 265(1), 155-166.

Lima, J., Avila, R., Abrao, A., Faustino, M. and Davim, J. P. (2005). Hard Turning: AISI 4340 High Strength Low Alloy steel and AISI D2 Cold Work Tool Steel. *Journal of Materials Processing Technology.* 169(3), 388-395.

Lin, Q., Zhang, Z. X. & Wang, Q. C. (2011). The Simulation and Experimental Study of Metal Cutting Based on Cold Air Technology. *Advanced Materials Research*. Trans Tech Publ, 242-247.

Liu, J. and Kevin Chou, Y. (2007). On Temperatures and Tool Wear in Machining Hypereutectic Al–Si Alloys with Vortex-Tube Cooling. *International Journal of Machine Tools and Manufacture.* 47(3), 635-645.

Liu, M., Takagi, J. I. and Tsukuda, A. (2004). Effect of Tool Nose Radius and Tool Wear on Residual Stress Distribution in Hard Turning of Bearing Steel. *Journal of Materials Processing Technology.* 150(3), 234-241.

Liu, N.-M., Chiang, K. T. and Hung, C.-M. (2013). Modeling and Analyzing the Effects of Air-Cooled Turning on the Machinability of Ti–6Al–4V Titanium Alloy using the Cold Air Gun Coolant System. *The International Journal of Advanced Manufacturing Technology.* 67(5-8), 1053-1066.

Llewellyn, D. and Hudd, R. (1998). *Steels: Metallurgy and Applications: Metallurgy and Applications.* Butterworth-Heinemann.

Malagi, R. & Rajesh, B. (2012). Factors Influencing Cutting Forces in Turning and Development of Software to Estimate Cutting forces in Turning. *Int J Eng Innov Technol.* 2, 14-30.

Moisan, A. L. (2000). Hard turning: Chip Formation Mechanisms and Metallurgical Aspects.

Montgomery, D. C. (2008). *Design and Analysis of Experiments*. John Wiley & Sons.

Morehead, M. D., Huang, Y. and Luo, J. (2007). Chip Morphology Characterization and Modeling in Machining Hardened 52100 Steels. *Machining Science and Technology.* 11(3), 335-354.

Najiha, M., Rahman, M. and Yusoff, A. (2016). Environmental Impacts and Hazards Associated with Metal Working Fluids and Recent Advances in the Sustainable Systems: A review. *Renewable and Sustainable Energy Reviews*. 60, 1008-1031.

Naves, V., Da Silva, M. and Da Silva, F. (2013). Evaluation of the Effect of Application of Cutting Fluid at High Pressure on Tool Wear During Turning Operation of AISI 316 Austenitic Stainless Steel. *Wear,* 302(1), 1201-1208.

Ng, E.G., Aspinwall, D.K., Brazil, D. and Monaghan, J. (1999). Modelling of Temperature and Forces when Orthogonally Machining Hardened Steel. *International Journal of Machine Tools and Manufacture*. 39(6), 885-903.

Ning, L., Veldhuis, S. and Yamamoto, K. (2008). Investigation of Wear Behavior and Chip Formation for Cutting Tools with Nano-Multilayered TiAlCrN/NbN PVD Coating. *International Journal of Machine Tools and Manufacture*. 48(6), 656-665.

Noordin, M.Y., Kurniawan, D., Tang, Y.C. and Muniswaran, K. (2012). Feasibility of Mild Hard Turning of Stainless Steel using Coated Carbide Tool. The *International Journal of Advanced Manufacturing Technology*. 60(9-12), 853-863.

Noordin, M., Venkatesh, V. and Sharif, S. (2007). Dry Turning of Tempered Martensitic Stainless Tool Steel using Coated Cermet and Coated Carbide Tools. *Journal of Materials Processing Technology*. 185(1), 83-90.

Noordin, M.Y., Venkatesh, V.C., Sharif, S., Elting, S. and Abdullah, A. (2004). Application of Response Surface Methodology in Describing the performance of Coated Carbide Tools when Turning AISI 1045 Steel. *Journal of Materials Processing Technology*. 145(1) 46-58.

Nordin, M., Sundström, R., Selinder, T. and Hogmark, S. (2000). Wear and Failure Mechanisms of Multilayered PVD TiN/TaN Coated Tools when Milling Austenitic Stainless Steel. *Surface and Coatings Technology*. 133, 240-246.

O’sullivan, D. and Cotterell, M. (2001). Temperature Measurement in Single Point Turning. *Journal of Materials Processing Technology*. 118(1),301-308.

Oberg, E. (2008). *Machinery's Handbook & Guide to Machinery's Handbook*, Industrial Press.

Obikawa, T., Kamata, Y. and Shinozuka, J. (2006). High-Speed Grooving with Applying MQL. *International Journal of Machine Tools and Manufacture*, 46(14), 1854-1861.

Ostwald, P.F. and Munoz, J. (2008). *Manufacturing Processes and Systems*. John Wiley & Sons.

Özel, T. (2009). Computational Modelling of 3D Turning: Influence of Edge Micro-Geometry on Forces, Stresses, Friction and Tool Wear in PcBN Tooling. J*ournal of Materials Processing Technology*. 209(11), 5167-5177.

Özel, T., Hsu, T.-K. and Zeren, E. (2005). Effects of Cutting Edge Geometry, Workpiece Hardness, Feed Rate and Cutting Speed on Surface Roughness and forces in Finish Turning of Hardened AISI H13 steel. *The International Journal of Advanced Manufacturing Technology.* 25(3-4), 262-269.

Patwari, M. A. U., Amin, A. N. and Faris, W. F. (2011). Influence of Chip Serration Frequency on Chatter Formation during End Milling of Ti6Al4V. *Journal of Manufacturing Science and Engineering.* 133(1), 011013.

Pervaiz, S., Rashid, A., Deiab, I. and Nicolescu, C. M. (2016). An Experimental Investigation on Effect of Minimum Quantity Cooling Lubrication (MQCL) in Machining Titanium Alloy (Ti6Al4V). *The International Journal of Advanced Manufacturing Technology*. 87(5-8), pp.1371-1386.

Pop, L., Puşcaş, C., Bandur, G., Vlase, G. and Nuţiu, R. (2008). Basestock Oils for Lubricants from Mixtures of Corn Oil and Synthetic Diesters. *Journal of the American Oil Chemists' Society.* 85(1), 71-76.

Poulachon, G., Moisan, A. and Jawahir, I. (2001a). On Modelling the Influence of Thermo-Mechanical Behavior in Chip Formation during Hard Turning of 100Cr6 Bearing Steel. *CIRP Annals-Manufacturing Technology*.50(1), 31-36.

Poulachon, G., Moisan, A. and Jawahir, I. (2001b). Tool-Wear Mechanisms in Hard Turning with Polycrystalline Cubic Boron Nitride Tools. *Wear,* 250(1), 576-586.

Poulachon, G. and Moisan, A. L. (2000). Hard Turning: Chip Formation Mechanisms and Metallurgical Aspects. *Journal of Manufacturing Science and Engineering.* 122(3), 406-412.

Pusavec, F., Lu, T., Courbon, C., Rech, J., Aljancic, U., Kopac, J. and Jawahir, I. (2016). Analysis of the Influence of Nitrogen Phase and Surface Heat

Transfer Coefficient on Cryogenic Machining Performance. *Journal of Materials Processing Technology.* 233, 19-28.

Qibiao, Y., Zhanqiang, L. and Bing, W. (2012). Characterization of Chip Formation during Machining 1045 Steel. *The International Journal of Advanced Manufacturing Technology.* 63(9-12), 881-886.

Quinn, L. (1992). Metalworking Fluids: at the Cutting Edge of Health and Safety. *ASTM Standardization News(USA).* 20(5), 40-43.

Raof, N. A., Ghani, J. A., Syarif, J., Che Haron, C. H. and Hadi, M. A. (2014). Comparison of Dry and Cryogenic Machining on Chip Formation and Coefficient of Friction in Turning AISI 4340 Alloy Steel. *Applied Mechanics and Materials*. 554,7-11. Trans Tech Publ.

Ravi, S. and Kumar, M. P. (2011). Experimental Investigations on Cryogenic Cooling by Liquid Nitrogen in the End Milling of Hardened Steel. *Cryogenics.* 51(9), 509-515.

Rech, J. and Moisan, A. (2003). Surface Integrity in Finish Hard Turning of Case-Hardened Steels. *International Journal of Machine Tools and Manufacture.* 43(5), 543-550.

Ren, J., LU, S., Ren, J. & Gong, S.(2006). A Study of Precision Sub-Dry Cutting Mechanism. *Key Engineering Materials*, 2006. Trans Tech Publ, 805-808.

Ren, J. L., Su, Y., Guan, X., Li, Y. & Wang, Q. (2010). Experimental Study on the Effect of Cold Air Cutting on Cutting Temperature, Cutting Force and Tool Wear during Machining of Cr12 Tool Steel. *Key Engineering Materials.* Trans Tech Publ, 334-337.

Rotella, G., Dillon JR, O., Umbrello, D., Settineri, L. and Jawahir, I. (2014). The Effects of Cooling Conditions on Surface Integrity in Machining of Ti6Al4V Alloy. *The International Journal of Advanced Manufacturing Technology.* 71(1-4), 47-55.

Rotella, G. and Umbrello, D. (2014). Finite Element Modeling of Microstructural Changes in Dry and Cryogenic Cutting of Ti6Al4V Alloy. C*IRP Annals-Manufacturing Technology.* 63(1), 69-72.

Saini, S., Ahuja, I. S. & Sharma, V. S. (2012). Residual Stresses, Surface Roughness, and Tool Wear in Hard Turning: a Comprehensive Review. *Materials and Manufacturing Processes.* 27(6), 583-598.

Salaam, H.A., Ye, P.S., Taha, Z., Ya, T. and Shah, T.M.Y.. (2013). The Effect of Vortex Tube Air Cooling on Surface Roughness and Power Consumption in Dry Turning. *In Applied Mechanics and Materials*. 310, 348-351. Trans Tech Publications.

Salem, S. B., Bayraktar, E., Boujelbene, M. and Katundi, D. (2012). Effect of Cutting Parameters on Chip Formation in Orthogonal Cutting. *Journal of Achievements in Materials and Manufacturing Engineering.* 50(1), 7-17.

Sales, W., Costa, L., Santos, S., Diniz, A., Bonney, J. & Ezugwu, E. (2009). Performance of Coated, Cemented Carbide, Mixed-Ceramic and PCBN-H Tools when Turning W320 Steel. *The International Journal of Advanced Manufacturing Technology.* 41(7)**,** 660-669.

Sandvik. (2016). Switch to Hard-Part Turning. *Trade Catalogue*.

Sarma, D. and Dixit, U. (2007). A Comparison of Dry and Air-Cooled Turning of Grey Cast Iron with Mixed Oxide Ceramic Tool. *Journal of Materials Processing Technology.* 190(1), 160-172.

Sasahara, H. (2005). The Effect on Fatigue Life of Residual Stress and Surface Hardness Resulting from Different Cutting Conditions of 0.45% C Steel. *International Journal of Machine Tools and Manufacture.* 45(2), 131-136.

Senthil Kumar, A., Raja Durai, A. and Sornakumar, T. (2006). The effect of Tool Wear on tool Life of Alumina-based Ceramic Cutting Tools while Machining Hardened Martensitic Stainless Steel. *Journal of Materials Processing Technology.* 173(2), 151-156.

Shankar, G., Shivaprakash, Y. M., Jayashree, P. K. and Sharma, S. S. (2013). Study on Chip-morphology in Turning of Ti-6Al-4V Alloy under High Pressure Neat oil and Soluble oil. *International Journal of Earth Sciences and Engineering*. 6(4), 832-837.

Sharif, S., Mohd Yusof, N., Idris, M., Ahmad, Z. A., Sudin, I., Ripin, A., Zin, M. and Hisyam, A. (2009). Feasibility Study of Using Vegetable Oil as a Cutting Lubricant Through the Use of Minimum Quantity Lubricant during Machining.

Sharif, S., Mohruni, A. S., Noordin, M. and Venkatesh, V. (2006). Optimization of Surface Roughness Prediction Model in End Milling Titanium Alloy (Ti-6Al4V). *Proceeding of ICOMAST2006, International Conference on*

Manufacturing Science and Technology. Faculty of Engineering and Technology, Multimedia University, Melaka, Malaysia, 55-58.

Sharma, V. S., Dogra, M. and Suri, N. (2009). Cooling Techniques for Improved Productivity in Turning. *International Journal of Machine Tools and Manufacture.* 49(6), 435-453.

Shashidhara, Y. and Jayaram, S. (2010). Vegetable Oils as a Potential Cutting Fluid—an Evolution. *Tribology International.* 43(5), 1073-1081.

Shaw, M. C. (2005). *Metal cutting principles*. (Vol.2). Oxford university press. New York.

Sheikh-Ahmad, J., Quarless, V. and Bailey, J. (2004). On the Role of Microcracks on Flow Instability in Low Speed Machining of CP Titanium. *Machining Science and Technology.* 8(3), 415-430.

Shihab, S. K., Khan, Z. A., Mohammad, A. and Siddiquee, A. N. (2013). Effect of Cutting Parameters on Cutting Forces and MRR during Turning Hard Alloy Steel With and Without Coolant. *International Journal of Engineering and Advanced Technology (IJEAT).* 3(1).

Shizuka, H., Sakai, K. and Suzuki, Y. (2009). The Assist Effect of Nitrogen Atmosphere on MQL Cutting Performance. *Key Engineering Materials.* 407, 321-324.

Shokrani, A., Dhokia, V., Muñoz-escalona, P. & Newman, S. T. (2013). State-of-the-Art Cryogenic Machining and Processing. *International Journal of Computer Integrated Manufacturing.* 26(7)**,** 616-648.

Shokrani, A., Dhokia, V. and Newman, S. T. (2012). Environmentally Conscious Machining of Difficult-to-Machine Materials with Regard to Cutting Fluids. *International Journal of Machine Tools and Manufactur*e. 57, 83-101.

Silva, L. R., Corrêa, E., Brandão, J. R. and De Ávila, R. F. (2013). Environmentally Friendly Manufacturing: Behavior Analysis of Minimum Quantity of Lubricant-MQL in Grinding Process. *Journal of Cleaner Production*.

Skerlos, S. J., Hayes, K. F., Clarens, A. F. and Zhao, F. (2008). Current Advances in Sustainable Metalworking Fluids Research. *International journal of sustainable manufacturing.* 1(1-2), 180-202.

Smith, G. T. (2008). *Cutting Tool Technology: Industrial Handbook*. Springer Science & Business Media.

Sobiyi, K. and Sigalas, I. (2015). Chip Formation Characterisation and Tem Investigation of Worn PcBN Tool during Hard Turning. *Machining Science and Technology.* 19(3), 479-498.

Sobiyi, K., Sigalas, I., Akdogan, G. and Turan, Y. (2015). Performance of Mixed Ceramics and CBN Tools during Hard Turning of Martensitic Stainless Steel. *The International Journal of Advanced Manufacturing Technology, 77(5-8), 861-871.*

Sourmail, T., and Bhadeshia, H. K. D. H. *Stainless Steel*. www.msm.cam.ach.uk/ phase - trans/2005/Stainless_Steels/Stainless.html. *Accessed on Feb. 20, 2014*.

Sreejith, P. S. and Ngoi, B. K. A. (2000). Dry Machining: Machining of the Future. *Journal of Materials Processing Technology*. 101(1), 287-291.

Srithar, A., Palanikumar, K. and Durgaprasad, B. (2014). Experimental Investigation and Surface Roughness Analysis on Hard Turning of AISI D2 Steel using Coated Carbide Insert. *Procedia Engineering*. 97, 72-77.

Stanford, M., Lister, P., Morgan, C. and Kibble, K. (2009). Investigation into the Use of Gaseous and Liquid Nitrogen as a Cutting Fluid when Turning BS 970-80A15 (En32b) Plain Carbon Steel using WC–Co Uncoated Tooling. *Journal of Materials Processing Technology.* 209(2), 961-972.

Stanford, M., Lister, P. M. and Kibble, K. A. (2007). Investigation into the Effect of Cutting Environment on Tool Life During the Milling of a BS970-080A15 (En32b) Low Carbon Steel. *Wear.* 262(11), 1496-1503.

Stephenson, D. A. & Agapiou, J. (1997). *Metal Cutting Theory and Practice*. New York.

Su, Y., He, N. and Li, L. (2010). Effect of Cryogenic Minimum Quantity Lubrication (CMQL) on Cutting Temperature and Tool Wear in High-Speed End Milling of Titanium Alloys. *Applied Mechanics and Materials*. 34, 1816-1821. Trans Tech Publications.

Su, Y., He, N., Li, L., Iqbal, A., Xiao, M., Xu, S. and Qiu, B. (2007). Refrigerated Cooling Air Cutting of Difficult-to-Cut Materials. *International Journal of Machine Tools and Manufacture.* 47(6), 927-933.

Su, Y., He, N., Li, L. and Li, X. (2006). An Experimental Investigation of Effects of Cooling/Lubrication Conditions on Tool Wear in High-Speed End Milling of Ti-6Al-4V. *Wear*. 261(7), 760-766.

Suresh, R., Basavarajappa, S., Gaitonde, V. and Samuel, G. (2012). Machinability Investigations on Hardened AISI 4340 Steel using Coated Carbide Insert. *International Journal of Refractory Metals and Hard Materials.* 33, 75-86.

Thamizhmanii, S. and Hasan, S. (2010). Relationship between Flank Wear and Cutting Force on the Machining of Hard Martensitis Stainless Steel by Super Hard Tools. *Proceedings of the World Congress on Engineering, 2010. World Congress on Engineering.* 3, 2185-2190.

Tönshoff, H. K., Arendt, C. and Amor, R. B. (2000). Cutting of hardened steel. *CIRP Annals-Manufacturing Technology*. 49(2),.547-566.

Trent, E. M. and Wright, P. K. (2000). *Metal cutting*. Butterworth-Heinemann.

Uddeholm, B. A. 2004. Stavax ESR. *North America,* catalogue.

Ulutan, D. and Ozel, T. (2011). Machining Induced Surface Integrity in Titanium and Nickel Alloys: A Review. *International Journal of Machine Tools and Manufacture.* 51(3), 250-280.

Umbrello, D. and Filice, L. (2009). Improving Surface Integrity in Orthogonal Machining of Hardened AISI 52100 Steel by Modeling White and Dark Layers Formation. *CIRP Annals-Manufacturing Technology.* 58(1), 73-76.

Umbrello, D., Micari, F. and Jawahir, I. S. (2012). The Effects of Cryogenic Cooling on Surface Integrity in Hard Machining: A Comparison with Dry Machining. *CIRP Annals-Manufacturing Technology*. 61(1), 103-106.

Umbrello, D., Pu, Z., Caruso, S., Outeiro, J., Jayal, A., Dillon, O. and Jawahir, I. (2011). The Effects of Cryogenic Cooling on Surface Integrity in Hard Machining. *Procedia Engineering.* 19, 371-376.

Varadarajan, A. (2013). *Investigations on Surface Milling of Hardened AISI4340 Steel with Minimal Fluid Application using a High Velocity Pulsed Jet of Cutting Fluid*. PhD thesis. Karunya University. India

Venkatesh, V. C. (1980). Tool wear Investigations on Some Cutting Tool Materials. *Journal of Lubrication Technology*. 102(4), 556-559.

Venkatesh, V. & Chandrasekaran, H. (1987). Experimenal Techniques in Metal Cutting. *Prentice Hall of India, 1987***,** 525.

Venkatesh, V., YE, C., Quinto, D. & Hoy, D. E. (1991). Performance Studies of uncoated, CVD-coated and PVD-Coated Carbides in Turning and milling. *CIRP Annals-Manufacturing Technology,* 40**,** 545-550.

Vyas, A. and Shaw, M. (1999). Mechanics of Saw-Tooth Chip Formation in Metal Cutting. *Journal of Manufacturing Science and Engineering.* 121(2), 163-172.

Wan, Z. P., Zhu, Y. E., Liu, H. W. and Tang, Y. (2012). Microstructure Evolution of Adiabatic Shear Bands and Mechanisms of Saw-tooth Chip Formation In Machining Ti6Al4V. *Materials Science and Engineering: A*. 531, 155-163.

Wang, C., Xie, Y., Zheng, L., Qin, Z., Tang, D. and Song, Y. (2014). Research on the Chip Formation Mechanism during the High-Speed Milling of Hardened Steel. *International Journal of Machine Tools and Manufacture.* 79, 31-48.

Wang, J. L., Cai, L. and Zheng, H. T. (2011). Experiment Study of Oil-Air Lubrication on Cooling of Turning Tools. *Advanced Materials Research*. 189, 3187-3190.

Wang, J. & Liu, C. (1998). A new Concept for Decoupling the Cutting Forces due to Tool Flank Wear and Chip Formation in Hard Turning. *Machining Science and Technology*. 2, 77-90.

Weinert, K., Inasaki, I., Sutherland, J. and WakabayashI, T. (2004). Dry Machining and Minimum Quantity Lubrication. *CIRP Annals-Manufacturing Technology*. 53(2), 511-537.

Weisend, J.G. ed. (1998). *Handbook of Cryogenic Engineering.* (Vol. 325). Philadelphia: Taylor & Francis.

Williams, J. and Tabor, D. (1977). The Role of Lubricants in Machining. *Wear,* 43(3), 275-292.

Xavior, M. A. and Adithan, M. (2009). Determining the Influence of Cutting Fluids on Tool Wear and Surface Roughness during Turning of AISI 304 Austenitic Stainless Steel. *Journal of Materials Processing Technology*. 209(2), 900-909.

Xue, Y., Arjomandi, M. and Kelso, R. (2013). The working Principle of a Vortex Tube. *International Journal of Refrigeration.* 36(6), 1730-1740.

Yallese, M. A., Chaoui, K., Zeghib, N., Boulanouar, L. and Rigal, J. F. (2009). Hard Machining of Hardened Bearing Steel using Cubic boron Nitride Tool. *Journal of Materials Processing Technology.* 209(2), 1092-1104.

Yan, L., Yang, W., Jin, H. and Wang, Z. (2012). Analytical Modelling of Microstructure Changes in the Machining of 304 Stainless Steel. *The*

International Journal of Advanced Manufacturing Technology. 58(1-4), 45-55.

Yang, Y., Tong, M. & Wu, Z. (2004). Effects of Cryogenic Cold Air Jet Cutting on Chip Break in Metal Machining. *Journal of Chongqing University (English Edition)*. 3(1), 6-10.

Yazid, M. Z. A., CheHaron, C. H., Ghani, J. A., Ibrahim, G. A. and Said, A. Y. M. (2011). Surface Integrity of Inconel 718 when Finish Turning with PVD Coated Carbide Tool under MQL. *Procedia Engineering*. 19, 396-401.

Yildiz, Y. and Nalbant, M. (2008). A Review of Cryogenic Cooling in Machining Processes. *International Journal of Machine Tools and Manufacture.* 48(9), 947-964.

Yuan, S. M., Liu, S. and Liu, W. D. (2012). Effects of Cooling Air Temperature and Cutting Velocity on Cryogenic Machining of 1Cr18Ni9Ti Alloy. A*pplied Mechanics and Materials.* 148, 795-800. Trans Tech Publ

Zeman, A., Sprengel, A., Niedermeier, D. and Späth, M. (1995). Biodegradable Lubricants—Studies on Thermo-Oxidation of Metal-Working and Hydraulic Fluids by Differential Scanning Calorimetry (DSC). *Thermochimica Acta.* 268, 9-15.

Zhang, S., Li, J. and Wang, Y. (2012). Tool Life and Cutting Forces in End Milling Inconel 718 under Dry and Minimum Quantity Cooling Lubrication Cutting Conditions. *Journal of Cleaner Production.* 32, 81-87.

Zhang, Y., Han, R. D., Tang, Y. L. and Wang, Y. (2010). Investigation of Water Vapor as Green Coolant and Lubricant in Turning of Austenitic Stainless Steel. *Key Engineering Materials.* 431, 409-412.

Zhang, Y., Sun, T. L., Li, Q. D. & Zhang, X. C. (2011). A Capillary Model for Gasesas Coolant and Lubricant in Metal Cutting. *Key Engineering Materials*. Trans Tech Publ, 167-172.