OPTIMISING THE OPERATIONAL PARAMETERS AND CONDITIONS TO ENHANCE THE ENVIRONMENTAL SUSTAINABILITY OF TURNING OPERATION

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Degree of Master of Science

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Thesis submitted in partial fulfillment of the requirements for the degree Master of Science by Research in Engineering

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DECLARATION

I declare that this is my own 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.

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

Name of the supervisor: Dr. J. R. Gamage

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ABSTRACT

The manufacturing sector accounts for nearly 40% and 25% of global energy and resources consumption respectively. The die and mould manufacturing (DMM) sector, contributes largely to the energy and resource consumption in emerging economies. Turning is a popular and essential mode of machining within this sector. Furthermore, operational energy usage and metalworking fluid (MWF) consumption of turning have been identified as the key sources of environmental impacts in this process. However, there is a lack of evidence on analysing environmental impacts of lathe operations in the DMM sector compared to milling operation. Therefore, the purpose of this study is to identify and analyse the life cycle environmental impacts of the commercial turning operation. A series of case studies was conducted in DMM centres to explore the state-of-the-art industrial turning operation. Then, a set of experiments was designed using the Taguchi L_9 method, considering the mostly used workpiece material, cooling condition and cutting parameters. Experiments were performed to evaluate the energy consumption, metalworking fluid (MWF) consumption, surface roughness and material removal rate during turning of AISI P20 with both wet and dry machining. A life cycle assessment (LCA) was performed using SimaPro LCA software with Ecoinvent database version 8.5 to assess the environmental performance of turning. A multi-response optimisation was performed using Grey-based Taguchi method to identify the optimum operating conditions. The results show that turning with wet machining yields better machining and environmental performances compared to dry machining. The largest portion of the energy is consumed for non-productive operations. The LCA results reveals electrical energy as the highest contributor under most of the impact categories. The workpiece material, AISI P20 and cutting insert material show significant contributions to aquatic ecosystems and resource consumption. However, the contribution of MWF on the midpoint impact categories is negligible. Further, the research presents optimum turning parameters to obtain better machining performances while maintaining lower environmental footprint in the context of turning of AISI P20 with wet machining.

Keywords: Sustainable machining, Life cycle assessment, Environmental impact, Turning operation

DEDICATION

I dedicate this thesis to my loving father, *Roy Antony Fernando*, and my mother, *Mary Juliet Kostha*, who guided me always to this achievement. Furthermore, I would like to dedicate this to my elder brothers, *Prasanna Fernando* and *Chamley Fernando*, who supported me to make this work success. Finally, I would like to dedicate this to my loving husband, *Anton Rexi Croos*, for staying with me all the time and encouraged me to this achievement.

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
AC	Air Conditioning
ADP	Abiotic Depletion Potential
AISI	American Iron and Steel Institute
Al_2O_3	Aluminium Oxide
ANOVA	Analysis of variance
AP	Acidification Potential
BOD	Biological Oxygen Demand
CC	Climate change
CFC	Chlorofluorocarbon
CH_4	Methane
Cl	Chlorine
CNC	Computer Numerical Control
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COVID-19	Coronavirus Disease 2019
CT	Confirmation Test
CV	Coefficient of Variation
CVD	Chemical Vapour Deposition
DCB	Dichlorobenzene
DMM	Die and Mould Manufacturing
DOC	Dissolved Organic Carbon
DOE	Design of Experiments
FAEP	Freshwater Aquatic Toxicity Potential
FD	Fossil resource scarcity
FE	Freshwater eutrophication
FET	Freshwater ecotoxicity
GRG	Grey Relational Grade

GWP	Global Warming Potential
H_3BO_3	Boric Acid
HPJAM	High Pressure Jet Assisted Machining
HTc	Human toxicity: cancer
HTnc	Human toxicity: non-cancer
HTP	Human Toxicity Potential
IR	Ionising radiation
ISO	International Organization of Standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
LN_2	Liquid Nitrogen
LO	Land use
MDL	Modified Digital Logic
ME	Marine eutrophication
MET	Marine ecotoxicity
MoS_2	Molybdenum Disulphide
MQL	Minimum Quantity Lubrication
MRD	Mineral resource scarcity
MRR	Material Removal Rate
MWF	Metalworking Fluid
N_2O	Dinitrogen Monoxide
Na	Sodium
NH_3	Ammonia
NH_4	Ammonium Carbonate
NIOSH	National Institute of Occupational Safety and Health
NMVOC	Non Methane Volatile Organic Carbon compound
NO_3	Nitrate
NO_x	Nitrogen Oxides
OD	Ozone depletion

ODP	Stratospheric ozone depletion potential
OECD	Organization for Economic Co-operation and Development
PAH	Polycyclic Aromatic Hydrocarbons
PCBN	Polycrystalline Cubic Boron Nitride
PM	Particulate Matter
PMF	Fine particulate matter formation
PO_4	Phosphate
POFE	Photochemical oxidant formation: Terrestrial ecosystems
POFH	Photochemical oxidant formation: Human health
PROSA	Product Sustainability Assessment
PVD	Physical Vapour Deposition
Ra	Arithmetical mean surface roughness
RSM	Response Surface Methodology
SD	Standard Deviation
SEM	Standard Error of the Mean
SLCA	Social Life Cycle Assessment
SO_2	Sulphur Dioxide
TA	Terrestrial acidification
TET	Terrestrial ecotoxicity
Ti	Titanium
TiAlN	Titanium Aluminium Nitride
TiCN	Titanium Carbon Nitride
TiN	Titanium Nitride
TOC	Total Organic Carbon
USA	United States of America
WC	Tungsten Carbide
WD	Water use

LIST OF NOMENCLATURE

Symbol	**Definition**	**Units**
a_p	Depth of cut	mm
E	Energy consumption	kWh
E_{ac}	Energy consumption by air conditioning system	kWh
E_c	Cutting Energy	kWh
E_{co}	Changeover Energy	kWh
E_l	Energy consumption by lights	kWh
E_m	Machining Energy	kWh
E_{nm}	Non-machining Energy	kWh
E_{total}	Total Energy	kWh
ε	Distinguishing coefficient	
f	Feed rate	mm/rev
i	Operating condition	
j	Responses	
k	Total number of responses	
MWF_c	MWF Consumption	ml
n	Spindle speed	rev/min
N	Possible decisions	
η	Signal to noise ratio	
t	Time	
t_c	Cutting Time	s
t_{co}	Changeover Time	s
t_m	Machining Time	s
t_{nm}	Non-machining Time	s
V_c	Cutting speed	m/min
Z_{ij}	Normalized signal to noise ratio	
α	Weighting factor	
γ_{ij}	Grey relation coefficient	
Δ_i	Deviation sequences	
$\bar{\gamma}_i$	Grey relational grade	