

Assessment of Product Sustainability through Different Optimization Techniques

Melesse Workneh Wakjira

A Dissertation submitted to

The Department of Mechanical Design and Manufacturing Engineering

School of Mechanical Chemical and Material Engineering

Presented in Fulfillment of the Requirement for the Degree of **Doctor of Philosophy** in
Manufacturing Engineering (Specialization in Sustainable Manufacturing)

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

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Melesse Workneh Wakjira

Pro. Dr. Ing. Habil Dr.h.c.mult. Holm Altenbach

(Main Advisor – Germany)

Asso. Pro. Dr. Perumalla Janaki Ramulu

(Co Advisor – Ethiopia)

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Declaration

I hereby declare that this PhD Dissertation is an authentic record of my own work; carried out from October, 2015 to May 2019, under the supervision of Prof. Dr. Ing. Habil Holm Altenbach and Asso. Prof. Dr. Perumalla Janaki Ramulu. To the best of my knowledge and belief, the dissertation contains no material previously submitted for a degree in any other university, and all sources of material used for this dissertation have been duly acknowledge.

Melesse Workneh

Signature

Date

This PhD Dissertation has been submitted for examination with our approval as dissertation Supervisor.

Pro. Dr. Ing. Habil Dr.h.c.mult. Holm Altenbach: (Main Supervisor, OVGU, Germany)

Signature

Asso. Prof. Dr. Perumalla Janaki Ramulu: (Co-Supervisor, ASTU, Ethiopia)

Signature

Date of submission: _____

Supervisor's approval sheet

To: The department of Mechanical Design and Manufacturing Engineering

Subject: PhD Dissertation Submission

This is to certify that the dissertation entitled "**Assessment of Product Sustainability through different Optimization Techniques**" submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Manufacturing Engineering specialization in Sustainable Manufacturing, the Graduate program of the department of Mechanical Design and Manufacturing Engineering, and has been carried out by Melesse Workneh Wakjira Id. No. GSR/1544/08, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby he can submit the dissertation to the department.

Pro. Dr. Ing. Habil Holm
Altenbach

(Main Advisor, Germany)

Date

Asso. Pro. Dr. Perumalla Janaki
Ramulu

(Co – Advisor, Ethiopia)

Date

Approved by Board of Examiners

_____	_____	_____
Chairman, Department Graduate Committee	Signature	Date
_____	_____	_____
Chairman, School of MCME Committee	Signature	Date
_____	_____	_____
Main Advisor	Signature	Date
_____	_____	_____
Co – Advisor	Signature	Date
_____	_____	_____
Internal Examiner	Signature	Date
_____	_____	_____
External Examiner	Signature	Date

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LIST OF NOMENCLATURE

PARAMETER	Descriptions	UNITS
A	Initial yield stress of the material at room temperature	MPa
A_u	uncut area is the rate at which the tool is	mm^2
B	fed The hardening modulus	MPa
C	Coefficient dependent on the strain rate	-
\mathbf{C}	Damping matrix	-
C_{ce}	Cost per cutting edge	\$
C_{cu}	Capacity utilization cost	\$
C_d	Depth of cut	mm
C_f	Feed factor	-
C_{rav}	average circumference of ring shaped removed	-
C_{tu}	material Tool utilization cost	\$
C_{up}	A unit production cost	\$
d	Diagonal of square-based pyramid diamond indenter	-
d_1	Initial failure strain	-
d_2	Exponential factor	-
d_3	Triaxiality factor	-
d_4	Strain rate factor	-
d_5	Temperature factor	-
\mathbf{D}	Strain rate tensor	-
D_{av}	Average diameter of the	mm
D_m	workpiece final machined	mm
D_o	diameter an annular	mm
e	ring of initial diameter Specific internal energy	J
E		-
ETOTAL	Machine tool efficiency factor Total energy	J
f	Frequency of respondents	-

F	Force matrix	-
F_c	Cutting or Power force	Newton
	Feed force	Newton
	Feed rate	mm/rev
F_t	Trust or radial force	Newton
	Body forces	Newton
	Fracture energy per unit area	J
HV	Hardness measured value	-
K	Stiffness matrix	-
K_c	Function of fracture toughness	-
K_P	Power constant	-
m	Liker type scale value	(1,2,3,4,5)
m	Thermal softening	-
m_c	Machining cost	\$
M	Mass matrix	-
MR	Material Removal Rate	mm ³ /min
R	Weight of material	mm ³ /s
MR_w	removed Machine	-
m_{ur}	utilization rate	pcs
n	Number of data point	rev/min
N	Rotational speed of the	-
O_m	Machining overhead	\$/ min
P_{ct}	Power at the cutting	Watt
P_m	Machining power	Watt
P_{mo}	Power at the motor	Watt
P_s	Specific energy required to remove a volume of material per time	Ws/mm ³
P_{Tn}	Total number of products made	pcs
P_{up}	Total power required for unit production	Watt
P	Idle machine power	Watt
x	Body heat generation	-
...		
S/N	Signal-to-Noise ratio	dB

T	Tool life	second
t_c	Cycle times to remove the material during machining	second
t_f	Finishing time	second
t_i	Starting time	second
t_m	Machining time	second
T_{melt}	Melting temperature of the workpiece	°C
T_{room}	Room temperature	20°C
T_{c_opt}	Optimum tool life for minimum unit production cost	second
T_{t_opt}	Optimum tool life for minimum unit production time	second
T^n	Angular speed (Torque)	Nm
T_{w_opt}	Optimum tool life for minimum unit production power consumption criterion	second
t_s	Setup time	second
t_{tc}	Time needed to change a worn cutting edge with a new one	min
t_{Tr}	Total tool replacement time	second
t_{up}	A unit production time	second
1	Function of tool-workpiece material	-
	Heat flux vector	-
	Cauchy stress tensor	-
$\cdot\cdot$	Contraction of a pair of repeated indices	-
	Density	kg/m ³
U	Displacement matrix	-
	Equivalent plastic strain rate	-
	Equivalent plastic strain	-
	Equivalent stress	N/mm ²
e	Estimated S/N ratio	dB
\bullet	Material derivative in a Lagrangian description	-
	Mean S/N ratio at the optimal level	dB
X	Mean value	-

	Reference strain rate	-
	Summation	-
	Total mean S/N ratio	dB
	Vector of acceleration in time (t)	$\frac{m}{s^2}$
	Vector of internal forces applied in time (t) Newton	
	integration step	-
	Damage parameter to initiate failure when it equals to 1	-
	Equivalent plastic displacement	mm
	Equivalent strain to fracture	-
p	Optimum cutting speed for minimum unit production power consumption criterion	m/min
	Plastic displacement at failure	-
	The average of the three normal stresses	MPa
		N/mm ²
	Von Mises equivalent stress	MPa
	Material velocity	m/s
	Optimum cutting speed for minimum unit production cost	m/min
	Optimum cutting speed for minimum unit production time	m/min
	Vector of external forces applied in time (t) Newton	
		N/mm ²
	Std. Deviation	-
	Volume	(cm ³ /mm ³)
	Poisson' ratio	-

$$\{F^{int}\}$$

$$\Delta \varepsilon^p$$

D

$$u^p$$

$$\varepsilon^p$$

$$V_{c-P_{ap}-OPT}$$

$$u_f$$

$$\sigma$$

$$\sigma_{y_0}$$

$$V_{c-C_{ap}-OPT}$$

$$V_{c-t_{ap}-OPT}$$

$$\{F^{ext}\}$$

$$V$$

$$v$$

Accumulated increment of equivalent plastic strain during an

Value of yield stress at the time when the failure criterion is reached

	Cutting speed	m/min
W	Tool wear factor	-
	Weight of material after machining	mm^3/s
W_i	Weight of material before	mm^3/s
X_i	Each of the value of data point	-
	Measured value of quality characteristics for i^{th} , trial condition	-

LIST OF ACRONYMS AND ABBREVIATIONS

3D	Three Dimensional
ABMI	Akaki Basic Metal Industry
ANOVA	Analysis of Variance
CNC	Computerized Numerical Control
CRPP	Customer Relationships Problems of the Product
DOE	Design of Experiment
DRSP	Delivery Reliability to Supply the Product
EEA	Ethiopian Energy Authority
ERN	European Remanufacturing Network
G4	Fourth Generation
GHG	Greenhouse Gas
GTP	Growth and Transformation Plan
GWP	Global Warming Potential
Hex	Hexahedron
HMMBI	Hibret Manufacturing and Machine Building Industry
METEC	Metal Engineering Corporation
MRR	Material Removal Rate
MS	Manufacturing Sustainability
OAs	Orthogonal Arrays
OEM	Original Equipment Manufacturer
OPPP	Operations Process Problems of the Product
PC	Product Cost
PQ	Product Quality
R&D	Research and Development
SCFP	Supply Chain Flexibility of the Product
SCM	Supply Chain Management
SCPQ	Supply Chain capability in the base of Product Quality
SPSS	Statistical Package for Social Science
SRPP	Supplier Relationship Problems of the Product

LIST OF PUBLICATIONS

JOURNALS

[1] Melesse Workneh Wakjira, Holm Altenbach and Perumalla Janaki Ramulu, Optimization of Manufacturing Sustainability in the Ethiopian Industries. Journal of Manufacturing

[2]Wakjira M.W., Altenbach H., Ramulu P.J. (2019) CSN 12050 Carbon Steel Mechanical Property Enhancement Using Thermal Treatment to Optimize Product Sustainability. In: Zimale F., Enku Nigussie T., Fanta S. (eds) Advances of Science and Technology. ICAST 2018. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 274. Springer, Cham

[3] Melesse Workneh Wakjira, Holm Altenbach and Perumalla Janaki Ramulu, Analysis of CSN 12050 Carbon Steel in Dry Turning Process for Product Sustainability Optimization using Taguchi Technique, Hindawi Journal of Engineering Volume 2019, Article ID 7150157,

CONFERENCES

[1] 15th Global Conference on Sustainable Manufacturing (GCSM), 25th–27th September, Engineering.

[2] 6th International Conference on the Advancements of Science and Technology (6th

PAPERS UNDER REVIEW

Melesse Workneh Wakjira, Holm Altenbach, Perumalla Janaki Ramulu, Product Sustainability Optimization through Remanufacturing Process.

Melesse Workneh Wakjira, Holm Altenbach, Perumalla Janaki Ramulu, Mechanics of Cutting Analysis in Turning Process to Optimize Product Sustainability.

Melesse Workneh Wakjira, Holm Altenbach, Perumalla Janaki Ramulu, Optimization of Cutting Speed and Tool Life for Economic and Minimum Power Consumption during Turning Process.

ABSTRACT

Product sustainability in manufacturing industry has become one of the main objectives for achieving environmental friendly production, with reduced cost. A generic model aspect presents and investigates the correlation for descriptive survey validation of manufacturing sustainability, which intends to investigate the correlation among benefits, drivers, barriers and triple bottom lines. The results can provide executive awareness of the current complex relations and to the development of an implementation plan. Thereby, it is possible to upgrade the level of a supply chain management, production, environmental efficiency and lead to strengthen government policy. The case study was done on the remanufacturing process at Hibret Manufacturing and Machine Building Industry (HMMBI), that aimed to investigate the knowhow about remanufacturing. The survey used an approach of quantifying economic turnover, job opportunities, and CO₂ emission reduction size. Methods used to determine CSN

*12050 carbon steel product sustainability optimization: (a) Chemical composition examination, microstructure and mechanical property testing through thermally treated, temperature-dependent process and untreated specimen, using Spectro test TXC25, muffle furnace, RB 206 Metpress-A, RB 204 Metpol-II, Polisher, Ethanol and nitric acid, Metallurgical Microscope, Vickers Hardness tester, and WP310 50KN universal material tester machine, respectively. The temperature-dependent process (recrystallized) sample **leads to** ease of machinability; (b) Experimentation and validation using Taguchi Orthogonal Array, mathematical and statistical analysis (ANOVA), as a result the S/N ratio optimum process control parameter is obtained at $A_3B_2C_3$; (c) Investigation of material removal rate experimental result data along with mathematical analysis of cutting parameters to achieve the optimum cutting force and reduced power consumption; (d) Mathematical formulation and modelling an optimum cutting speed with the corresponding tool life based on unit production time/cost considering minimum time, cost and power consumption criterion; and (e) Finite Element Method (FEM) modeling and simulations with Lagrangian approach together with Johnson-Cook (JC) material model has been used to simulate chip morphology and to predict the optimum conditions. Specially, the comparison between untreated, annealed and recrystallized CSN 12050 carbon steel material mechanical property experimentation and FEA simulation analysis result were conducted efficiently and achieved a good agreement. The achieved outcome of the research work creates an essential ground and important contribution particularly; for HMMBI, Ethiopia, and other developing countries for the implementation of product sustainability optimization philosophy. An investigations of manufacturing processes/system, development of sustainable product standards, product design by incorporating with remanufacturing concepts, modelling for an energy efficient materials and FEM combined with the experimental validations will be recommended for future works.*

Keywords: *Product-sustainability-optimization, Triple-bottom-lines, HMMBI, remanufacturing, Chemical-composition, Thermal-treatment, Microstructure, mechanical-property, Taguchi-Orthogonal-Array, FEM, Chip-morphology*