DEVELOPMENT OF A SPUR GEAR FROM CARBURISED CAST IRON FOR APPLICATION IN BOTTLING MACHINES

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SEPTEMBER, 2020

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN MECHANICAL ENGINEERING, IN THE DEPARTMENT OF MECHANICAL ENGINEERING, COLLEGE OF ENGINEERING, COVENANT UNIVERSITY, OTA.

SEPTEMBER, 2020

ACCEPTANCE

This is to attest that this thesis is accepted in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy (Ph.D) in Mechanical Engineering in the Department of Mechanical Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria.

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DECLARATION

I, **SALAWU ENESI YEKINI (17PCM01599),** declare that this research was carried out by me under the supervision of Prof. Oluseyi O. Ajayi and Prof. Anthony O. Inegbenebor of the Department of Mechanical Engineering, College of Engineering, Covenant University, Ota, Ogun State and Dr. Stephen Akinlabi of the Department of Mechanical Engineering, Walter Sisulu University, Butterworth Eastern Cape, South Africa. I attest that the thesis has not been presented either wholly or partially for the award of any degree elsewhere. All sources of data and scholarly information used in this thesis are duly acknowledged.

SALAWU, ENESI YEKINI **…………………………………**

Signature and Date

CERTIFICATION

We certify that this thesis titled **"Development of a Spur Gear from Carburised Cast Iron for Application in Bottling Machines"** is an original work carried out by **SALAWU, ENESI YEKINI (17PCM01599),** in the Department of Mechanical Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria, under the supervision of Prof. Oluseyi O. Ajayi, Prof. Anthony O. Inegbenebor and Dr. Stephen Akinlabi. We have examined and found this work acceptable as part of the requirements for the award of a Doctor of Philosophy (Ph. D) degree in Mechanical Engineering.

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(Dean, School of Postgraduate Studies) Signature and Date

DEDICATION

This research is dedicated to my mother and my late father for their sacrifice, love, and support.

ACKNOWLEDGEMENTS

I want to sincerely give glory and honor to the Almighty God, the maker of heaven and earth, the one that gave me the vision and guidance throughout my career. He made it possible through the prayers of my late father to meet someone that took me as his son and friend. What else do I have to offer to this great author of the Universe? I am a product of divine favour through the prayers and prophecies of my late father. I will forever be grateful to you, Lord.

My appreciation goes to the Chancellor of this highly esteemed institution, Dr. David O. Oyedepo, for the vision that birthed this commission and institution and for the excellent opportunity given to me to study in this God's own University. God bless you, sir. To the management of Covenant University, ably led by Prof. Aaron. A. A. Atayero, thank you for creating this good platform for me to become an established academic. Also, to the Deputy Vice-Chancellor, Prof. Akan. B. Williams, the Registrar, Dr. Oluwasegun J. Omidiora, the Dean SPS, Prof. Abiodun H. Adebayo, the Sub-Dean SPS, Prof. Obinna C. Nwinyi and the Dean College of Engineering, Prof. David O. Omole. Thank you all for your supports. To the management of Intercontinental Distillers Limited, thank you for the privilege of working with you for years. Indeed, the wealth of experience gained had led to the success of this research, and for collaborating with the University on this research, I am grateful. To my good friends from the company, Engr. Clement Anetor, Okesade Ayo, thank you for your beautiful contributions towards the success of this work.

To my supervisor, Prof. Oluseyi O. Ajayi, words are not enough to describe your love for me and my career. God has used you to bless people. God brought you my way to show me how to discover my talent and put them to use and become blessed. You may be a model to others, but you are a complete icon of joy to me, my family, and my career. I thank God for the energy, skill, and zeal He gave to you to impact upon me up to this stage. I have tried to learn from your humility and attitude, and I know God will bestow me with them as I approach the altitude of greatness. My sincere appreciation to my co-supervisors, first to Prof. Anthony O. Inegbenebor, a father who did not only supervise but nurtured me on the way to integrate the fundamentals of materials' properties into the work. Indeed, you are a father to me. To my second co-supervisor, Dr. Stephen Akinlabi, who ensured that my journey to South Africa was successful.

You made sure the experimental work was supervised at the University of Johannesburg. And to your wife, Prof. Esther Akinlabi, thank you for the beautiful environment and your students you provided who eventually became my brothers. To my supervisors, once again, you are the set of humans that my father prayed for to lift me in life, and I am glad that God fulfilled his prayers and prophecy for me through you. To the Head of Mechanical Engineering Department, Prof. Joshua O. Okeniyi, I sincerely appreciate your honest effort towards the structuring and quality required to ensure that this research was a success. My appreciation to the College Postgraduate Coordinator, Dr. Isaac A. Samuel and the Departmental Postgraduate Coordinator, Dr. Olugbenga A. Omotosho. Also, my sincere gratitude to Prof. A.P.I. Popoola for the provisions you made for the pre-characterisation of my samples at the Tshwane University of Technology, Pretoria, South Africa.

The immense contributions of Dr. Ojo Sunday Fayomi and Prof. Sunday Oyedepo are highly appreciated. Your constructive criticisms and contributions during the research are valued. Also, my appreciation goes to Dr. Richard Leramo, Dr. Sunday. A. Afolalu, Dr. Abiodun A. Abioye, Dr. Philip Babalola, Dr. Oluwaseun Kilanko, Prof. Loto Roland, Dr. Ongbali Samson and Dr. Funmi Joseph for your beautiful contributions. I will not forget my colleagues with whom we started this journey together. Engr. Azeta Joseph, Engr. Joseph Dirisu, Engr. Fajobi Muyiwa, Engr. Imhade Okokpujie, Engr. Abioye Oluwabunmi and Engr. Ndoye Ekene. God bless you all. Also to Engr. Felix Ishola and Engr. Aworinde Abraham, God bless you. To my only sister, Mrs. Queen Adeyeye, and your lovely husband, Babatunde Adeyeye, I say thank you for being there for me always.

To my late father, thank you for your sacrifice, I write in tears knowing how well you tried to make me a better child, but you never waited to enjoy the fruit of your labour; my wonderful and hardworking father. I promise to be of significant impact to people as that had been your full dream. Thank you, Daddy, rejoice in heaven for your prayer of love for me has come to pass. To my kind, patient and humble mother, my father told me that you would live to enjoy the fruit of your labour. Indeed, I am glad you are alive to witness the end of this achievement. Thank you for the effort you made for me to start school. You will live long, mum.

How well can I say thank you, my precious wife, Mrs. Blessing Juliana Salawu. No matter how lowly I felt, you have always been there to say it is well. Thanks for being my best friend. To my beautiful children, Victor Emmanuel and Joy Emmanuel, thanks for being my most excellent friends and playmates all through this journey. My appreciation goes to my nephew Michael Salawu for being there always, and my siblings Ojo and Onayi, God bless you all. To my colleagues and friends and people whose names are not mentioned, I appreciate you all, and God bless you all.

CONTENT **TABLE OF CONTENT** **Page**

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

LIST OF SYMBOLS

r_{EF}	the vector which points from E to F
ξ	angle vector between vector n_A
H	maximum height of contour of the actual tooth surface, mm
Δt	time step for numerical integration
φ	free parameter
Δz	dimension of tangential stiffness made at the direction across oil film
$\Delta F_r(t)$ *and* $\Delta X_r(t)$	increased tangential displacement
$K_r(t)$	oil film tangential stiffness
t	time variables
B	face width
X_r	tangential deformation
Δ^k	grid spacing along rolling direction (m)
X	horizontal coordinate (m)
Z	vertical coordinate (m)
σ_{eff}	equivalent stress
σ_i *and* σ_{ii}	normal and tangential stress
T^{bulk}	bulk temperature
ΔT	change in bulk temperature
[M]	mass matrix
[C]	damping matrix
[K]	stiffness matrix
[F]	force vector containing motor torque, load, and friction
Δa	crack growth
E	Young's modulus
J	j-integral
f	void volume fraction
T_0	cohesive work of separation
σ_0	initial yield stress

σ_c	cohesive strength
C_c	carbon concentration in mol/cm^3
T	temperature in K
z	distance from the source to the receiver
a	half-line length
λ	wavelength
$\mathcal{S}$	Fresnel parameter
m	module of gear
s	tooth thickness of the gear
d	reference diameter of gear teeth
z	number of teeth
da	tip diameter of the gear
ha	addendum
hf	dedendum
(c)	tip and root clearance of the gear teeth
df	root diameter
t_1	the temperature at the top surface of the gear tooth
t_2	the temperature at the root surface of the gear tooth
z_1	coordinate of the particle at the tip of gear tooth
z_2	coordinate of the particle at the root of gear tooth
K	thermal conductivity of mild steel given as 54 W/mk
Q_z	heat transfer
A	cross-sectional area of the gear tooth

LIST OF ACRONYMS AND ABBREVIATIONS

DSC−	Digital Scanning Calorimetry
EDS−	Energy Dispersive Spectroscopy
PLC−	Programmable Logic Controller
SEM−	Scanning Electron Microscopy
TEM−	Transmission Electron Microscopy
TGA−	Thermal Gravimetric Analysis
XRD−	X-ray Dispersive Spectroscopy

ABSTRACT

Spur gears are components used in power transmission in bottling machines. Bottling machine breakdowns are often the result of spur gear failure, and the cause of gear failure can stem from many issues, of which the most common is failure due to wear. This study, therefore, developed a spur gear with adequate mechanical properties that can function in such an environment. Pareto and metallurgical techniques were used to characterise the failure and its effects on the production process and equipment reliability. A mechanistic design approach was employed to simulate the casting process using proCAST software before the casting of the blank. The third stage involves the experimental casting, testing, and characterisation of the developed material and its comparative analyses with characterised mild steel results. The blank cast was sectioned into coupons for carburisation using palm kernel shell, coconut shell, and wood charcoal at different temperatures of 700°C, 800°C, and 900°C at different holding time of 60, 90, 120 and 180 minutes respectively using eggshell as an energiser. Optimised samples were characterised using spark spectrometer, scanning electron microscope integrated with energy dispersive spectroscopy (SEM/EDS), X-ray diffraction (XRD). The microhardness test was evaluated using Vicker's hardness tester, while wear test was done using sliding wear tester, and the thermal gravimetric analyses were equally carried out. All tests and methods were carried out according to the American Society for Testing and Materials (ASTM). The result of the 3D surface analyser showed variation in wear distribution with some zones under intense material erosion. The result of the analysed failure data revealed that about forty-three thousand two-hundred products (43,200), which translates to a 100 % loss in operation for a day (24 hours). From the result of carburisation, all samples showed a homogenous absorption of carbon at the interface for each of the carburising media. The microstructures of each sample revealed the presence of iron and carbon at the interface, and chromium and nickel which improved the corrosion resistance of the developed material. More so, samples carburised using the three carburisers revealed improved hardness properties, with palm kernel shell having an improved hardness value of 355 HV against the as-received grey cast iron and other media. Improved wear and friction were demonstrated by each sample as well as excellent electrochemical characteristics with grey cast iron showing a lower corrosion rate and weight loss of 0.0007 and 0.0008 mg for samples tested in 28 % and 43 % ethanol blend concentration respectively. Results from the performance evaluation of the developed gear showed that there is a significant improvement in the machine reliability and productivity with 183.33 % output for total operating hours of 620. The improvement in the mechanical properties of developed samples due to the homogenous diffusion of carbon at the interface of surface asperities verified their suitability in engineering applications. Thus, organic carbon is an excellent enhancer of the mechanical properties of metals.

Keywords: Carburisation, Design, Failure, Gears, Machines, Production