

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

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SEPTEMBER, 2020

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IRON FOR APPLICATION IN BOTTLING MACHINES**

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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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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
COVER PAGE		i
TITLE PAGE		ii
ACCEPTANCE		iii
DECLARATION		iv
CERTIFICATION		v
DEDICATION		vi
ACKNOWLEDGEMENTS		vii
LIST OF FIGURES		xvi
LIST OF TABLES		xxi
LIST OF PLATES		xxii
LIST OF SYMBOLS		xxiii
LIST OF ACRONYMS AND ABBREVIATIONS		xxv
ABSTRACT		xxvii
1 CHAPTER ONE: INTRODUCTION		1
1.1 Background to the Study		1
1.2 Statement of Problem		4
1.3 Aim and Objectives		6
1.4 Scope of the Study		7
1.5 Justification of the study		7
2 CHAPTER TWO: LITERATURE REVIEW		10
2.1 Gear Wear Characteristics		10
2.2 Mild Steel		17
2.3 Cast Iron		19
2.4 Carburisation Process		25
2.5 Annealing Process		30
2.6 Brief Description of Bottling Machines		33
3 CHAPTER THREE: METHODOLOGY		46
3.1 Materials		46
3.1.1 Mild steel		46
3.1.2 Grey cast iron		46
3.1.3 Pulverised palm kernel shell		47

3.2	Methods	50
3.2.1	Sectioning of the failed spur gear teeth	50
3.2.2	Characterisation of the failed spur gear teeth (mild steel as control)	50
3.2.3	Blank casting design and simulation using proCAST	50
3.2.4	Blank casting using sand casting process	51
3.2.5	Characterisation of the cast material	51
3.2.6	Electrochemical study	51
3.2.7	Characterisation of the samples subjected to electrochemical study	51
3.2.8	Characterisation of the organic carbon content	52
3.2.9	Sieving of the organic carbon	52
3.2.10	Carburisation process	53
3.2.11	Composition analysis of carburised samples	53
3.2.12	Spur gear design calculation	53
3.2.13	Determination of the effects of downtime on the machine	55
3.2.14	Modelling the effect of variation in temperature around the gear Tooth	55
4	CHAPTER FOUR: RESULTS	56
4.1	Chemical Composition of as-received Mild Steel	57
4.2	Chemical composition of as-received grey cast iron	57
4.3	Composition analysis of sample carburised with pulverised coconut shell	58
4.4	Composition analysis of sample carburised in pulverised palm-kernel shell	59
4.5	Results of failure of mild steel gear and its effect on production line	59
4.6	Analyses of the gear failure on the production line using Pareto technique	62
4.6.1	Analyses of the defect count for production line 1	62
4.6.2	Analyses of the cost of defect for production line 1	62
4.6.3	Analyses of the defect count for production line 2	63
4.6.4	Analyses of the cost defect for production line 2	64
4.6.5	Analyses of the defect count for production line 3	64
4.6.6	Analyses of the cost of defect for production line 3	65
4.7	Analysis of the effects of Alcoholic Beverages on the Gear Material	65
4.7.1	Mild steel in different concentrations of ethanol test solution	65
4.7.2	Potentiodynamic results of distilled water solution (control test)	66
4.7.3	Potentiodynamic study of mild steel in different test solution	66
4.7.4	Potentiodynamic weight loss for various mild steel samples	67
4.7.5	Daily experimental weight loss plot for mild steel samples	67
4.7.6	Average experiment weight loss plot for mild steel samples	68

4.7.8	Potentiodynamic weight loss measurement	68
4.7.9	Static immersion weight loss measurements results	68
4.7.10	Average weight loss measurement	71
4.8	SEM/EDS Analyses	71
4.8.1	SEM/EDS analyses of as-received mild steel after corrosion test	71
4.8.2	SEM/EDS analyses of mild steel immersed in distilled water	72
4.8.3	SEM/EDS analyses of mild steel immersed in 42 % alcohol concentration	73
4.8.4	SEM/EDS analyses of mild steel immersed in 40 % alcohol concentration	74
4.8.5	SEM/EDS analyses of mild steel immersed in 28 % alcohol concentration	75
4.8.6	SEM/EDS analyses of mild steel in (Sample D)	76
4.8.7	SEM/EDS analyses of mild steel immersed in 43 % alcohol concentration	77
4.8.8	SEM/EDS analyses of mild steel immersed in (sample F)	78
4.8.9	SEM/EDS analyse of as-received grey cast iron	79
4.8.10	SEM/EDS analyses of grey cast iron immersed in distilled water	80
4.8.11	SEM/EDS analyses of grey cast iron in 42% alcohol concentration	82
4.8.12	SEM/EDS analyses of grey cast iron in 40% alcohol concentration	83
4.8.13	SEM/EDS analyses of grey cast iron in 28% alcohol concentration	84
4.8.14	SEM/EDS analyses of grey cast iron in 42% alcohol (sample D)	85
4.8.15	SEM/EDS analyses of grey cast iron in 43% alcohol concentration	86
4.8.16	SEM/EDS analyses of grey cast iron in 42% alcohol (sample F)	87
4.9	SEM/EDS Result of Carburised Grey Cast Iron Samples	88
4.9.1	SEM/EDS of as-received grey cast iron	88
4.9.2	SEM/EDS of grey cast iron carburised in palm kernel shell at 900°C	89
4.9.3	SEM/EDS of grey cast iron carburised in palm kernel shell at 800°C	90
4.9.4	SEM/EDS of grey cast iron carburised in palm kernel shell at 700°C	91
4.9.5	SEM/EDS of grey cast iron carburised in wood charcoal at 900°C	92
4.9.6	SEM/EDS of grey cast iron carburised in wood charcoal at 800°C	93
4.9.7	SEM/EDS of grey cast iron carburised in wood charcoal at 700°C	94
4.9.8	SEM/EDS of grey cast iron carburised in coconut shell at 900°C	95
4.9.9	SEM/EDS of grey cast iron carburised in coconut shell at 800°C	96
4.9.10	SEM/EDS of grey cast iron carburised in coconut shell at 700°C	97
4.10	XRD Analyses	98
4.10.1	XRD analyses of the bio-based carbon	98
4.10.2	XRD analysis of the carburised grey cast iron in coconut shell at 700°C	99
4.10.3	XRD analysis of the carburised grey cast iron in coconut shell at 800°C	99

4.10.4	XRD analysis of the carburised grey cast iron in coconut shell at 900°C	99
4.10.5	XRD analysis of the carburised grey cast iron in wood charcoal at 700°C	101
4.10.6	XRD analyses of the carburised grey cast iron in wood charcoal at 800°C	101
4.10.7	XRD analyses of the carburised grey cast iron in wood charcoal at 900°C	101
4.10.8	XRD analyses of carburised grey iron in palm kernel shell at 700°C	103
4.10.9	XRD analyses of carburised grey cast iron in palm kernel shell at 800°C	103
4.10.10	XRD analyses of carburised grey iron in palm kernel shell at 900°C	103
4.11	TEM analyses of the carburisers	105
4.12	Thermal Gravimetric Analysis	106
4.12.1	DSC-TGA curves of mild steel immersed in distilled water	106
4.12.2	DSC-TGA curves of sample B (immersed in 40 % ethanol concentration)	106
4.12.3	DSC-TGA curves of sample C (immersed in 28 % ethanol concentration)	106
4.12.4	DSC-TGA curves of sample E (immersed in 43 % ethanol concentration)	106
4.12.5	DSC-TGA curves of sample F (immersed in 43 ethanol concentration)	106
4.12.6	DSC-TGA curves of grey cast iron immersed in distilled water	109
4.12.7	DSC-TGA curves of grey cast iron immersed in 42% concentration	109
4.12.8	DSC-TGA curves of grey cast iron immersed in 40% concentration	111
4.12.9	DSC-TGA curves of grey cast iron immersed in 28% concentration	111
4.12.10	DSC-TGA curves of grey cast iron (D) immersed in 42 % concentration	111
4.12.11	DSC-TGA curves of grey cast iron immersed in 43% concentration	111
4.12.12	DSC-TGA curves of grey cast iron (F) immersed in 42% concentration	111
4.13	Hardness Behaviour	114
4.13.1	As- received mild steel and after corrosion tests	114
4.13.2	Micro-hardness of as-received grey cast iron and after corrosion test	114
4.13.3	Micro-hardness behaviour of carburised grey cast iron	115
4.14	Wear Analyses of Mild steel and Grey Cast Iron	116
4.14.1	As-received mild steel	116
4.14.2	As-received grey cast iron	116
4.14.3	Plot of force against time for carburised cast iron in palm kernel at 900°C	117
4.14.4	COF with time for carburised grey cast iron in palm kernel at 900°C	117
4.14.5	Plot of force with time for carburised grey iron in wood charcoal at 900°C	117
4.14.6	COF with time for carburised grey cast iron in wood charcoal at 900°C	118
4.14.7	Plot of force with time for carburised grey iron in coconut shell at 900°C	118
4.14.8	COF with time for carburised grey cast iron in coconut shell at 900°C	120
4.15	Turbulence flow simulation using proCAST	121

4.15.1	Blank and gating system design	121
4.15.2	Variation in temperature of molten metal during pouring	121
4.15.3	Solid fraction formation during pouring of molten metal	122
4.15.4	Fraction of solid formation during pouring of molten metal	122
4.15.5	Solidification time of molten metal during pouring	122
4.15.6	Time to solidus of molten metal during pouring	123
4.15.7	Measure of shrinkage porosity in molten metal during pouring	123
4.15.8	Thermal modulus of molten metal during pouring	123
4.15.9	Formation of hot spot of molten metal during pouring	125
4.15.10	Interfacial heat transfer coefficient of molten metal during pouring	125
4.15.11	Fluid flow velocity of molten metal during pouring	126
4.15.12	Measure of fluid flow in U-direction	126
4.15.13	Measure of fluid flow in V-direction	126
4.15.14	Measure of fluid flow in W-direction	126
4.15.15	Turbulent energy of the mould during pouring	128
4.15.16	Measure of turbulent kinetic energy during pouring	128
4.15.17	Measure of turbulent viscosity during pouring	129
4.16	Production of the Spur Gear	130
4.16.1	Variation of operating hours with months	130
4.16.2	Variation of income with months	130
4.17	Modelling the Effect of Temperature Distribution around the Gear Tooth	131
4.17.1	Spur gear tooth in mesh	131
4.17.2	Plot of temperature with heat transfer rate	132
4.17.3	Variation of temperature with Z_1 coordinate	132
4.17.4	Variation of temperature with Z_2 coordinate	133
4.17.5	Variation of heat transfer rate with Z_1 coordinate	133
4.17.6	Variation of heat transfer rate with Z_2 coordinate	133
5	CHAPTER FIVE: DISCUSSION	136
5.1	Chemical composition analyses	136
5.1.1	As-received mild steel	136
5.1.2	As-received grey cast iron	136
5.1.3	Chemical composition of Grey cast iron samples after carburisation	136
5.2	Results of failure of mild steel gear and its effect on production line	137
5.3	Impact of the Gear Failure on the Production Line using Pareto Technique	138
5.4	Mild Steel in the different Concentration of Ethanol Test Solution	139

5.4.1	Weight loss measurements after potentiodynamic test	139
5.4.2	Weight loss measurements	140
5.4.3	Grey cast iron in the different concentration of ethanol test solution	140
5.4.4	Potentiodynamic weight loss measurement	140
5.4.5	Static immersion weight loss measurements results	141
5.5	SEM/EDS Analyses	141
5.5.1	SEM/EDS analyses of as-received mild steel after corrosion test	141
5.5.2	SEM/EDS analyses of grey cast iron after the corrosion test	144
5.5.3	SEM/EDS result of carburised grey cast iron samples	145
5.6	XRD analyses	147
5.6.1	XRD analysis of the carburising media	147
5.6.2	XRD analyses of the carburised grey cast iron	147
5.7	TEM Analyses of the Carburisers	149
5.8	Thermal Gravimetric Analyses	150
5.8.1	Mild steel	150
5.8.2	Thermal gravimetric analyses of grey cast iron	151
5.9	Hardness Behaviour	152
5.9.1	As- received mild steel after corrosion tests	152
5.9.2	Micro-hardness of as-received grey cast iron after corrosion test	153
5.9.3	Micro-hardness behaviour of carburised grey cast iron	153
5.10	Wear Analyses of Mild Steel and Grey Cast Iron	154
5.10.1	As-received mild steel	154
5.10.2	As-received grey cast iron	154
5.10.3	Wear behaviour of carburised grey cast iron	154
5.11	Turbulence flow Simulation using proCAST	156
5.12	Production of the Spur Gear	158
5.13	Modeling the effect in temperature distribution around the gear tooth	159
6	CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS	163
6.1	SUMMARY	163
6.2	CONCLUSION	163
6.3	CONTRIBUTIONS TO KNOWLEDGE	166
6.4	RECOMMENDATIONS	167
	REFERENCES	168
	APPENDIX	199

LIST OF FIGURES

Figure	Title of Figure	Page
1.1	Pictorial view of the failed teeth of a spur gear during an operation (Salawu et al, 2015)	5
1.2	Monthly failure rate of spur gear in the year 2017	6
1.3	A cross section of spur gear teeth	9
2.1	Typical 3 in 1 Bottling machine (rinser, filler and capper) (S S Packaging Industries)	34
2.2	Labelling machine (S S Packaging Industries)	35
2.3	Spur Gears Terminology (Khurmi and Gupta, 2005)	37
2.4	Different variations of Pitting failure (Liang et al, 2017)	37
2.5	Scoring Failure (machinerylubrication.com)	38
2.6	Slotting Failure (machinerylubrication.com)	38
2.7	Moderate wear (machinerylubrication.com)	39
2.8	Excessive wear (machinerylubrication.com)	39
2.9	Abrasive wear (machinerylubrication.com)	40
2.10	Corrosive wear (machinerylubrication.com)	40
2.11	Frosting (machinerylubrication.com)	40
2.12	Spalling formation mechanism in Spur Gears	41
2.13	Tooth flank fracture (machinerylubrication.com)	41
4.1	Pictorial view showing the failed gear teeth	60
4.2	Optical micrograph of (a) Tooth 1, 4.2 (b) Tooth 2 and 4.2 (c) Tooth 3	61
4.3	3D Surface plot for (a) Tooth 1, 4.3 (b) Tooth 2 and 4.3 (c) Tooth 3	61
4.4	comparison of the defect count against the type of defect for production line 1	62
4.5	Comparison of the cost of defect against type of defect for production line 1	63
4.6	Comparison of the defect count against the type of defect for production line 2	63
4.7	Comparison of the cost of defect against type of defect for production line 2	64
4.8	Comparison of the cost of defect against type of defect for production line 3	64
4.9	Comparison of the cost of defect against type of defect for production line 3	65
4.10	Potentiodynamic polarization behaviour of test solutions on mild steel	66
4.11	Potentiodynamic weight loss for various samples	67
4.12	Daily experimental weight loss plot	67
4.13	Average experimental weight loss plot	69
4.14	Potentiodynamic polarisation behaviour of test solutions on Grey cast iron	69
4.15	Potentiodynamic weight loss of as received grey cast iron in different concentration of test solutions	70

4.16	Daily weight loss plot	70
4.17	Average weight loss plot	71
4.18	SEM/EDS showing the surface morphology of as-received mild steel sample	72
4.19	SEM/EDS showing the surface morphology of mild steel in distilled water (control sample)	73
4.20	SEM/EDS showing the surface morphology of mild steel in 42 % alc. vol. concentration (sample A)	74
4.21	SEM/EDS showing the surface morphology of mild steel in 40 % alc. Vol concentration (sample B)	75
4.22	SEM/EDS showing the surface morphology of mild steel in 28 % alc. Vol concentration (sample C)	76
4.23	SEM/EDS showing the surface morphology of mild steel in 42 % alc. Vol concentration (sample D)	77
4.24	SEM/EDS showing the surface morphology of mild steel in 43 % alc. Vol concentration (sample E)	78
4.25	SEM/EDS showing the surface morphology of mild steel in 42 % (Schnapp) alc. Vol concentration (sample F)	79
4.26	SEM/EDS showing the surface morphology as-received grey cast iron	80
4.27	SEM/EDS showing the surface morphology grey cast iron (distilled water) Control test solution	81
4.28	SEM/EDS showing the surface morphology of grey cast iron in 42% alc. Vol concentration (sample A)	82
4.29	SEM/EDS showing the surface morphology of grey cast iron in 40% alc. Vol concentration (sample B)	83
4.30	SEM/EDS showing the surface morphology of grey cast iron in 28% alc. Vol concentration (sample C)	84
4.31	SEM/EDS showing the surface morphology of grey cast iron in 42% alc. Vol concentration (sample D)	85
4.32	SEM/EDS showing the surface morphology of grey cast iron in 43% alc. Vol concentration (sample E)	86
4.33	SEM/EDS showing the surface morphology of grey cast iron in 42% alc. Vol. concentration (sample F)	87
4.34	SEM/EDS Morphology As-received Grey cast iron	88
4.35	SEM/EDS Morphology of Grey cast iron sample in Palm-kernel shell Carburised at 900°C for 3hours	89
4.36	SEM/EDS Morphology of Grey cast iron sample in Palm-kernel shell Carburised at 800°C for 3hours	90
4.37	SEM/EDS Morphology of Grey cast iron Sample in Palm-kernel shell Carburised at 700°C for 3hours	91
4.38	SEM/EDS Morphology of Grey cast iron sample in wood charcoal Carburised at 900°C for 3hours	92

4.39	SEM/EDS Morphology of Grey cast iron sample in wood charcoal Carburised at 800°C for 3hours	93
4.40	SEM/EDS Morphology of Grey cast iron sample in wood charcoal Carburised at 700°C for 3hours	94
4.41	SEM/EDS Morphology of Grey cast iron sample in Coconut shell medium Carburised at 900°C for 3hours	95
4.42	SEM/EDS Morphology of Grey cast iron sample in Coconut shell medium Carburised at 800°C for 3hours	96
4.43	SEM/EDS Morphology of Grey cast iron sample in Coconut shell medium Carburised at 700°C for 3hours	97
4.44	XRD Profiles of (a) Egg shell, (b) Coconut shell, (c) Palm kernel shell and (d) Wood charcoal	98
4.45	XRD profile of sample in Coconut shell medium Carburised at 700°C for 3hours	99
4.46	XRD profile of sample in Coconut shell medium Carburised at 800°C for 3hours	100
4.47	XRD profile of sample in Coconut shell medium Carburised at 900°C for 3hours	100
4.48	XRD profile of sample in Wood charcoal medium Carburised at 700°C for 3hours	101
4.49	XRD profile of sample in Wood charcoal medium Carburised at 800°C for 3hours	102
4.50	XRD profile of sample in Wood charcoal medium Carburised at 900°C for 3hours	102
4.51	XRD profile of sample in Palm-kernel shell powder medium Carburised at 700°C for 3hours	103
4.52	XRD profile of sample in Palm-kernel shell powder medium Carburised at 800°C for 3hours	104
4.53	XRD profile of sample in Palm-kernel shell powder medium Carburised at 900°C for 3hours	104
4.54	(a) Egg shell, 4.54 (b) Coconut shell, 4.54 (c) Palm kernel shell and 4.54 (d) Wood charcoal	105
4.55	DSC-TGA Curves of sample in distilled water (Control sample)	107
4.56	DSC-TGA Curves of Sample B (After immersion in 40 % alc. vol. conc.)	107
4.57	DSC-TGA Curves of Sample C (After immersion in 28 % alc. vol. conc.)	108
4.58	DSC-TGA Curves of Sample E (After immersion in 43 % alc. vol. conc.)	108
4.59	DSC-TGA Curves of Sample F (After immersion in 43 % alc. vol. conc.)	109
4.60	DSC-TGA Curves of Control cast sample (in distilled water)	110
4.61	DSC-TGA Curves of Sample A (After immersion in 42 % alc. vol. conc.)	110

4.62	DSC-TGA Curves of Sample B (After immersion in 40 % alc. vol. conc.)	112
4.63	DSC-TGA Curves of Sample C (After immersion in 28 % alc. vol. conc.)	113
4.64	DSC-TGA Curves of Sample D (After immersion in 42 % rum alc. vol. conc.)	113
4.65	DSC-TGA Curves of Sample E (After immersion in 43 % rum alc. vol. conc.)	113
4.66	DSC-TGA Curves of Sample F (After immersion in 42 % alc. vol. conc.)	114
4.67	Plot of Micro-hardness values for the mild steel samples immersed in different test solutions	115
4.68	Plot of Micro-hardness for Grey cast iron samples immersed in different test solutions	115
4.69	Plot of Micro-hardness against samples at varying temperatures and constant time	116
4.70	Variation of Force with time for Carburised sample at 900°C for 3 hours using palm kernel shell powder	117
4.71	Variation of Coefficient of friction with time for Carburised sample at 900°C for 3 hours using palm kernel shell powder	118
4.72	Force against time for Carburised sample at 900°C for 3 hours using wood charcoal powder	119
4.73	Variation of Coefficient of friction with time for Carburised sample at 900°C for 3 hours using wood charcoal powder	119
4.74	Force against time for Carburised sample at 900°C for 3 hours using coconut shell powder	120
4.75	Variation of Coefficient of friction with time for Carburised Sample at 900°C for 3 hours using coconut shell powder	120
4.76	Blank and Gating system design	121
4.77	Variation in temperature	122
4.78	Formation of solid fraction	123
4.79	Variation in fraction of solid	124
4.80	Solidification Time	124
4.81	Time to Solidus	124
4.82	Variation in Shrinkage Porosity	125
4.83	Thermal modulus	125
4.84	Hot spot formation	126
4.85	Interfacial heat transfer coefficient	127
4.86	Fluid flow velocity	127
4.87	Fluid flow velocity in U-direction	127
4.88	Fluid flow velocity in V-direction	128
4.89	Fluid flow velocity in W-direction	128

4.90	Turbulent Energy	129
4.91	Turbulent Dissipation	129
4.92	Turbulent Viscosity	130
4.93	Plot of operating hours against the months of operation	131
4.94	Plot of income versus months of operation	132
4.95	Diagrammatic representation of a Spur gear tooth in mesh	132
4.96	Variation of Temperature with Heat transfer rate	133
4.97	Variation in Temperature with Z1 co-ordinate	134
4.98	Variation in Temperature with Z2 co-ordinate	134
4.99	Variation of Heat Transfer rate with Z1 Co-ordinate	135
4.100	Variation of Heat Transfer rate with Z2 Co-ordinate	135

LIST OF TABLES

Table	Title of Tables	Page
1.1	Revenue reduction analysis of a bottling line as at 2017	6
3.1	Properties of various Ethanol Blend solutions in the Study	49
4.1	Chemical composition of as-received mild steel	57
4.2	Chemical composition of as-received Grey cast iron	57
4.3	Composition analysis of sample carburised with Pulverised Coconut shell	58
4.4	Composition analysis of sample carburised with pulverised Wood Charcoal	58
4.5	Composition analysis of sample carburised with pulverised Palm-kernel shell	59
4.6	Potentiodynamic corrosion parameter of control sample in (distilled water)	66
4.7	Wear test result of as received mild steel sample	116
4.8	Wear test result of as received grey cast iron sample	117

LIST OF PLATES

Plates	Page
3.1 Pulverised Palm kernel shell	50
3.2 Pulverised Coconut shell	50
3.3 Pulverised Wood Charcoal	51
3.4 Pulverised Eggshell	51

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 film	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
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