



Cairo University

FAILURE ANALYSIS AND MODIFICATIONS OF CARBURIZED GEARS

BY

Eng.: Raafat Ibrahim Mohamed Goher

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In a Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

In

MECHANICAL DESIGN AND PRODUCTION ENGINEERING

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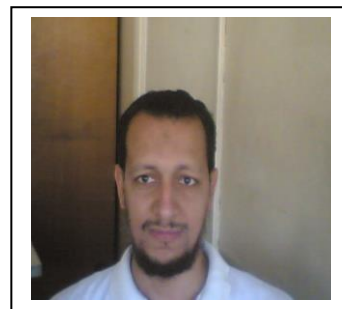
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Key Words: Gears failure; Carburizing; Decarburization; Case depth; 17NiCrMo 7-6; 14NiCr18

Summary:

The mechanical failure mainly concentrated in; material selection errors, design errors, production error and heat treatment errors with about 79 % of the total failure causes. Gear failure is one of the most important problems facing the gears' designers, manufacturers and maintenance team. Gear failure may occur due to the errors in design, manufacturing, operating conditions or maintenance. Design errors may also come due to errors in stress analysis, material selection, geometry analysis or heat treatment specifications. Manufacturing errors may be result from the machining accuracy and/or errors, geometrical errors, heat treatment errors, finishing errors or assembly errors.

In this work, three industrial gear failure cases were studied and analyzed. It was found that the most failure cases were resulting from the heat treatment specifications, implementation or design analysis. So, the study was aimed to analyzing the failure cases searching for its causes and introducing solutions to the discovered failure causes. The failure studied cases, were made of carburized materials so; the carburization technique of surface hardening was applied. The studied cases material was DIN 1.6587 (17NiCrMo 7-6). The failure reason of the first and second cases were due to errors of; the carburizing depth either less or more than the correct values and decarburization. Those errors were studied and solved. Whereas, the third failure case was due to the high applied stress to the gears. For this reason, the study aims to find a high strength material which can help in overcome more stresses than the above-mentioned material and it was found that the material DIN 1.5860 (14 Ni Cr 18) could do this. But since this material is coded as aerospace material and it has a shortage of, data and researches so, this material is subjected to a variety of heat treatment conditions for discovering the best conditions which verifying high strength, toughness and wear resistance. Sets of specimens were manufactured, heat treated under variable conditions and mechanically tested. For material 18CrNiMo7-6 the relation between, carburizing time and case depth was correlated. For material 14NiCr18, it could obtain high tensile and impact strengths at a certain carburizing and tempering conditions for both oil and water quenching media. Also, wear resistance was tested where good results are obtained.

ACKNOWLEDGEMENT

I present my deepest thanks and regards to the supervisors for their great help, advices, guidance and patience, which enabled me to complete this work and present it in an acceptable form.

It gives me a great pleasure to express my deepest thanks and sincere gratitude to Prof. Dr. Badr Azzam for his generous, kind, guidance and great effort to finish this work.

I'd like to express my deepest thanks to Prof. Dr. Mahmoud Abdrabou who enabled me to complete this work.

To the Memory of Prof. Dr. Mohamed Kamal Bedewy who guided me to the way of the scientific behavior and how the great scientist behaves with the research, problems and human being.

Also, I'd like to express my thanks to everyone who helped me in preparing this work even by encouraging word, especially my real honest colleagues and friends.

Finally, I express my special thanks to my family.

TABLE OF CONTENTS

AKNOWLEDGEMENT	I
TABLE OF CONTENTS	II
LIST OF TABLES	IV
LIST OF FIGURES	V
ABSTRACT	IX
 CHAPTER 1: INTRODUCTION	 1
1-1 Design considerations for gears.....	1
1-2 Gear failure problems	1
1-3 Gear materials	2
1-4 Heat treatment	2
1-5 The present work objectives	3
1-6 The study approach	3
1-7 Overview of the Thesis	5
 CHAPTER 2: LITERATURE SURVEY	 7
2-1 Introduction.....	7
2-2 Gear sliding wears	8
2-3 Gear dynamic wears	9
2-4 Gear load wears	10
2-5 Surface heat treatment	11
2-6 Carburized depth	13
2-7 Hardness	14
2-8 Tempering	15
2-9 Wear test	16
 CHAPTER 3: Gear Design and manufacturing	 17
3-1 Gear functions and loads.....	17
3-2 Factors affecting the gear loads.....	17
3-3 Gear materials	17
3-4 Gear heat treatments.....	18
3-4-1 Hardenability	19
3-4-2 Case hardening	19
3-4-3 Carburizing	20
3-4-4 Quenching	22
3-4-5 Tempering.....	24
3-5 Material testing	25
3-6 Gear manufacturing	25
3-7 Gear failures	27
3-8 The present work specifications	30
 CHAPTER 4: Experimental Work I Failure Analysis Cases	 32
4-1 Introduction to failure causes statistical survey	32
4-2 Introduction to failure cases	32
4-3 Research methodology	33
4-4 First Case Study “High Speed Driven Gear”	33
4-4-1 Observations and Review	34
4-4-2 Investigation	34
4-4-3 Results discussion	36

4-5	Second Case Study “Angle Head Spiral Gears”	37
4-5-1	Problem definition	38
4-5-2	Observations and review	38
4-5-3	Laboratory investigation	40
4-5-4	Results discussion	43
4-6	Third Case Study “High Stress Gear”	44
4-6-1	Problem definition	44
4-6-2	Observations and review	45
4-6-3	Laboratory investigation	46
4-6-4	Results discussion	49
4-6-4.1	The material, micro-hardness and microstructure	49
4-6-4.2	The stress analysis	50
4-7	Conclusions of the three case studies	51
CHAPTER 5:	Experimental Work II Failure Causes Modifications	52
5-1	Carburizing depth control for material 18CrNiMo7-6	52
5-1-1	Rejected Specimens	52
5-1-2	Accepted Specimens	56
5-1-3	The Modified Specimens	62
5-2	Material 14 NiCr18 (DIN NO 1.5860)	66
5-2-1	Specimens Dimensions	68
5-2-2	Accessories for testing machines design and manufacturing	69
5-2-3	Heat treatment procedure	72
5-2-4	First Stage	72
5-2-4-1	Water Quenched Specimens	73
5-2-4-2	Oil Quenched Specimens	79
5-2-5	Second Stage	84
5-2-6	Third Stage	90
5-2-7	Wear test	96
CHAPTER 6:	Results and Discussion	99
6-1	Failure Cases	99
6-1-1	First Case study results discussion	99
6-1-2	Second Case study results discussion	101
6-1-3	Third Case Study results discussion	101
6-2	Experimental work results discussion	104
6-2-1	Correlation the carburizing depth and carburizing time	104
6-2-2	Material (DIN 1.5860, 14NiCr18) results discussion	104
CHAPTER 7:	CONCLUSIONS AND RECOMMENDATIONS	111
7-1	CONCLUSIONS	111
7-2	RECOMMENDATIONS	112
REFERENCES		113
APPENDIX A: PUBLICATIONS		119
ملخص الرسالة		أ

LIST OF TABLES

Table (3.1) Machining faults and its reasons.	30
Table (3.2) Material 14NiCr18 chemical composition	31
Table (4.1) statistical survey study for failure causes	32
Table (4.2) Hardness through the gear tooth sections	35
Table (4.3) Original gear hardness values through the tooth sections	40
Table (4.4) Manufactured gear hardness values through the tooth sections	41
Table (4.5) Gears' data	45
Table (4.6) Gear hardness values through the tooth sections	47
Table (4.7) Case study parameters	49
Table (5.1) Rejected specimens' reasons	52
Table (5.2) Accepted specimens' data	59
Table (5.3) Comparison between the first phase model results and the actual results	61
Table (5.4) The second phase specimens' microhardness measurements	62
Table (5.5) The carburizing time and effective case depth results	64
Table (5.6) Comparison between; the second phase model and the actual; results	64
Table (5.7) First stage water quenched tensile test results	74
Table (5.8) First stage water quenched impact test results	75
Table (5.9) First stage water quenched microhardness measurements	75
Table (5.10) First stage tensile test results oil quenched	80
Table (5.11) First stage impact test results oil quenched	80
Table (5.12) First stage oil quenched microhardness measurements	81
Table (5.13) Second stage tensile tests results	85
Table (5.14) Second stage impact tests results	85
Table (5.15) Second stage microhardness measurements	86
Table (5.16) Third stage tensile test results	91
Table (5.17) Third stage impact test results	92
Table (5.18) Third stage micro-hardness measurements	93
Table (5.19) Results of wear test of the second stage specimens	97
Table (5.20) Results of wear test of the third stage specimens	98
Table (6.1) Conventional sector micro-hardness measurement	102
Table (6.2) Modified sector micro-hardness measurement	103

LIST OF FIGURES

Fig. (1.1) Gear Geometry	2
Fig. (1.2) Study plan	5
Fig. (2.1) Teeth contact surfaces and wear	7
Fig. (2.2) Example of pitting in gear teeth	9
Fig. (2.3) An excessive wear leads to vibration and failure	9
Fig. (2.4) Effect of load in wear loss	10
Fig (2.5) Planetary pinion teeth totally or partially failed due to fatigue failure	11
Fig (2.6) Gear Failure due to excessive retained austenite	12
Fig. (2.7) Quenching TTT Diagram	12
Fig. (2.8) Case depth and strength relation	14
Fig. (2.9) Tempering temperature and mechanical properties relation	15
Fig. (2.10) Tempering time and hardness relation	15
Fig. (3.1) TTT Diagram; A austenite, F ferrite, C carbide and M martensite	19
Fig. (3.2) Case depth proportions	19
Fig. (3.3) The iron–iron carbide phase diagram	20
Fig. (3.4) Carburizing temperature relation with toughness and tensile strength	21
Fig. (3.5) TTT diagram	22
Fig. (3.6) Double quenching process	23
Fig. (3.7) Conventional quenching process	23
Fig. (3.8) Fatigue strength in both conventional and double quenching processes	23
Fig. (3.9) Tempering temperature and hardness relation	24
Fig. (3.10) Hardness - Carbon - Tempering Temperature relation	24
Fig. (3.11) Gear hobbing cutter	26
Fig. (3.12) Gear hobbing machine	26
Fig. (3.13) Gear grinding machine	26
Fig. (3.14) Intergranular fracture	28
Fig. (3.15) Massive intergranular fracture	28
Fig. (3.16) Microhardness survey	29
Fig. (4.1) The gear after failure	34
Fig. (4.2) The gear after cut off for research	34
Fig. (4.3) Case tooth microstructure (excessive retained austenite) Nital 5%, 1000X	35
Fig. (4.4) Core microstructure (excessive retained austenite) +coarse martensite Nital 5%, 1000X	35
Fig. (4.5) Decarburization depth (white area) between teeth	36
Fig. (4.6) Microhardness vs. case depth	36
Fig. (4.7) Decarburization at the tooth root Nital 5%,200X	36
Fig. (4.8) TTT diagram	37
Fig. (4.9) Original gear teeth cracks	39
Fig. (4.10) Original gear keyway cracks	39
Fig. (4.11) Manufactured gears after failure	39
Fig. (4.12) Manufactured gear teeth breakage (1)	39
Fig. (4.13) Manufactured gear teeth breakage (2)	39
Fig. (4.14) Original gear microhardness	41
Fig. (4.15) Manufactured gear microhardness	42
Fig. (4.16) Original gear teeth surface microstructure	42
Fig. (4.17) Original gear teeth core microstructure	42
Fig. (4.18) Manufactured gear teeth surface shows excessive retained austenite	43
Fig. (4.19) Pinion gear teeth failure	45
Fig. (4.20) Pinion gear section failure	45
Fig. (4.21) Pinion gear pitting and failure	46
Fig. (4.22) Mating gear teeth pitting	46
Fig. (4.23) Pinion gear micro-hardness	47

Fig. (4.24) teeth surface shows tempered martensite with small amount of retained austenite	48
Fig. (4.25) Pinion gear teeth root microstructure	48
Fig. (4.26) Multi stage casing	50
Fig. (5.1) Specimen P239 microhardness survey	53
Fig. (5.2) Specimen P320 microhardness survey	53
Fig. (5.3) Specimen P377 microhardness survey	53
Fig. (5.4) Specimen P381 microhardness survey	54
Fig. (5.5) Specimen P383 microhardness survey	54
Fig. (5.6) Specimen P386 microhardness survey	54
Fig. (5.7) Specimen P389 microhardness survey	55
Fig. (5.8) Specimen P391 microhardness survey	55
Fig. (5.9) Specimen P393 microhardness survey	55
Fig. (5.10) Specimen P394 microhardness survey	56
Fig. (5.11) Specimen P260 microhardness survey	56
Fig. (5.12) Specimen P313 microhardness survey	57
Fig. (5.13) Specimen P365 microhardness survey	57
Fig. (5.14) Specimen P367 microhardness survey	57
Fig. (5.15) Specimen P370 microhardness survey	58
Fig. (5.16) Specimen P371 microhardness survey	58
Fig. (5.17) Specimen P372 microhardness survey	58
Fig. (5.18) Specimen P373 microhardness survey	59
Fig. (5.19) Specimen P398 microhardness survey	59
Fig. (5.20) Carburizing Time Depth Diagram	60
Fig. (5.21) Comparison between the actual and models results	61
Fig. (5.22) Second phase specimens	62
Fig. (5.23) Specimen M3 microhardness	68
Fig. (5.24) Specimen M4 microhardness	68
Fig. (5.25) Specimen M5 microhardness	68
Fig. (5.26) Specimen M6 microhardness	68
Fig. (5.27) Specimen M7 microhardness	68
Fig. (5.28) Specimen M8 microhardness	68
Fig. (5.29) Carburizing time and effective carburizing depth diagram	64
Fig. (5.30) Comparison between the actual and models results	65
Fig. (5.31) Specimen P403 micro-hardness survey	65
Fig. (5.32) Specimen P410 microhardness survey	66
Fig. (5.33) Hardness Vs. Carburizing depth	66
Fig. (5.34) Retained austenite Vs. Carburizing depth	67
Fig. (5.35) Hardness Vs. carburizing depth quenched at (- 196 Co)	67
Fig. (5.36) Retained austenite Vs. Carburizing depth at (- 196 Co)	67
Fig. (5.37) Tensile specimen drawings	68
Fig. (5.38) Impact specimen 6x6 mm	69
Fig. (5.39) Impact specimen 8x8 mm	69
Fig. (5.40) Specimen and tension fixture assembly	70
Fig. (5.41) Tension fixture adapted pare	70
Fig (5.42) Tension fixture Part 3	71
Fig. (5.43) Wear test machine fixture	72
Fig. (5.44) First stage test specimens water quenching	73
Fig. (5.45) First stage test specimens after heat treatment	73
Fig. (5.46) tensile test with special adaptation	74
Fig. (5.47) Impact test machine	74
Fig. (5.48) Tensile strength vs. carburizing time using water + soda quenching	74
Fig. (5.49) Impact strength vs. carburizing time using water + soda quenching	75
Fig. (5.50) Micro-hardness vs. specimen depth for 5hrs carburizing time water + soda quenching	76

Fig. (5.51) Micro-hardness vs. specimen depth for 6hrs carburizing time water + soda quenching	76
Fig. (5.52) Micro-hardness vs. specimen depth for 7hrscarburizing time water + soda quenching	76
Fig. (5.53) Micro-hardness vs. specimen depth for 8hrs carburizing time water + soda quenching	77
Fig. (5.54) Effective carburizing depth vs. carburizing time water + soda quenching	77
Fig. (5.55) Microstructure investigation and micro-hardness specimens	77
Fig. (5.56) First stage specimens micro-structure water and soda quenched-200x	78
Fig. (5.57) Heat treatment equipment lay out	79
Fig. (5.58) Charging the specimens to the carburizing furnace	79
Fig. (5.59) Tensile and impact specimens of the first stage second set after testing.	80
Fig. (5.60) Tensile strength vs. carburizing time oil quenched	80
Fig. (5.61) Impact strength vs. carburizing time oil quenched	81
Fig. (5.62) Microhardness and micro-structure specimens	81
Fig. (5.63) Microhardness vs. carburizing depth 3hrs carburizing oil quenched	82
Fig. (5.64) Microhardness vs. carburizing depth 4hrs carburizing oil quenched	82
Fig. (5.65) Microhardness vs. carburizing depth 6hrs carburizing oil quenched	82
Fig. (5.66) Microhardness vs. carburizing depth 7hrs carburizing oil quenched	83
Fig. (5.67) Case depth vs. carburizing time	83
Fig. (5.68) Second set microstructure – oil quenched 100x	84
Fig. (5.69) Second stage tempered specimens	84
Fig. (5.70) Tensile strength vs. tempering time	85
Fig. (5.71) Impact strength vs. tempering time	86
Fig. (5.72) Microhardness and microstructure specimens	86
Fig. (5.73) Microhardness vs. depth for oil quenched 0 hrs tempering	87
Fig. (5.74) Microhardness vs. depth for water quenched 0 hrs tempering	87
Fig. (5.75) Microhardness vs. depth for oil quenched 1 hrs tempering	87
Fig. (5.76) Microhardness vs. depth for water quenched 1 hrs tempering	88
Fig. (5.77) Microhardness vs. depth for oil quenched 2 hrs tempering	88
Fig. (5.78) Microhardness vs. depth for water quenched 2 hrs tempering	88
Fig. (5.79) Microhardness vs. depth for oil quenched 3 hrs tempering	89
Fig. (5.80) Microhardness vs. depth for water quenched 3 hrs tempering	89
Fig. (5.81) Microstructure of the second stage 100x	90
Fig. (5.82) The third stage tension specimens	91
Fig. (5.83) The third stage impact specimens	91
Fig. (5.84) Third stage tensile test results	92
Fig. (5.85) Third stage impact test results	92
Fig. (5.86) Microhardness and microstructure specimens	93
Fig. (5.87) Oil quenched first specimen microhardness	93
Fig. (5.88) Oil quenched first specimen microhardness	94
Fig. (5.89) Oil quenched first specimen microhardness	94
Fig. (5.90) Water quenched first specimen microhardness	94
Fig. (5.91) Water quenched first specimen microhardness	95
Fig. (5.92) Water quenched first specimen microhardness	95
Fig. (5.93) Microstructure of the third stage 100x	96
Fig. (5.94) Pin and Disc wear test machine	97
Fig. (5.95) Balance machine accuracy 0.001g	97
Fig. (5.96) Second stage wear vs. tempering time	98
Fig. (5.97) Third stage specimens wear	98
Fig. (6.1) Case #1 failure hardness measurements	100
Fig. (6.2) Case #1 teeth ductile failure	100
Fig. (6.3) TTT diagram nose avoidance	101
Fig. (6.4) Carburization difference experiment gear sector	101
Fig. (6.5) Conventional gear sector microhardness	102
Fig. (6.6) Modified gear sector microhardness	103

Fig. (6.7) Unused reduction gear stages in the gearbox casing	104
Fig. (6.8) First stage tensile strength vs. carburized time	105
Fig. (6.9) First stage impact strength vs. carburized time	105
Fig. (6.10) Second stage tensile strength vs. carburized time	106
Fig. (6.11) Second stage impact strength vs. carburized time	106
Fig. (6.12) Third stage tensile strength for the three specimens	107
Fig. (6.13) Third stage impact strength for the three specimens	107
Fig. (6.14) First stage water quenched specimens	107
Fig. (6.15) First stage oil quenched specimens	108
Fig. (6.16) First stage specimens S2/6 and S2/7 microhardness	108
Fig. (6.17) Second stage water & oil quenched specimens	108
Fig. (6.18) Third stage water & oil quenched specimens	109
Fig. (6.19) Suggested heat treatment layout	109
Fig. (6.20) Specimen 4-o-3 micro cracks 200X	110
Fig. (6.21) Specimen 4-w-3 micro cracks 200X	110

ABSTRACT

The mechanical failure responsibility mainly concentrated in; material selection errors, design errors, production errors and heat treatment errors with about 79 % of the total mechanical failure causes. Gears are important items of the mechanical components.

Gear failure is one of the most important problems facing the gear designers, manufacturers and maintenance team. Gear failure may occur due to the errors in design, manufacturing, operating conditions or maintenance. Design errors may also come due to errors in stress analysis, material selection, geometry analysis or heat treatment specifications. Manufacturing errors may be result from the machining accuracy and/or errors, geometrical errors, heat treatment errors, finishing errors or assembly errors. Maintenance errors may happen if the maintenance is not proper or is not carried out corresponding to the standards recommendations.

In this work, three industrial gear failure cases were studied and analyzed. It was found that the most failure cases were resulting from the heat treatment specifications, implementation or design analysis. So, the study was aimed to analyzing the failure cases searching for its causes and modifying the heat treatment operation to ensure optimal heat treatment specifications regarding the mechanical and tribological properties which led to the case of gear failure. The failure studied cases, were made of carburized materials so; the carburization technique of surface hardening was selected to apply the modifications. The studied cases material was DIN 1.6587 (17NiCrMo 7-6). The failure reason of the first and second cases were due to an error of the carburizing depth either less or more than the recommended values. This material heat treatment was studied to correlate the carburizing time with the carburizing depth in order to correctly validate the required case depth. Whereas, the third failure case was due to the high applied stress to the gears. For this reason, the study aims to find a high strength material which can help in overcome more stresses than the above-mentioned material and it was found that the material DIN 1.5860 (14 Ni Cr 18) could do this. But since this material is coded as aerospace material and it has a shortage of, data and researches so, a contribution of discovering its heat treatment procedure is done in this work. This material is subjected to a variety of heat treatment conditions for discovering the best conditions which verify high strength, toughness and wear resistance. Sets of specimens were manufactured, heat treated under variable conditions and mechanically tested. The results of the experimental work of both materials were satisfied concerning the objectives of each material experimental. For material 18CrNiMo7-6 the relation between, carburizing time and case depth was correlated. Two specimens were used to approve the resultant relation and it was satisfied with good accuracy. For material 14NiCr18, it could obtain high tensile and impact strengths at a certain carburizing and tempering conditions for both oil and water quenching media. Also, wear resistance was tested where good results are obtained.

Finally, the results of the industrial failure cases and the other experimental work could be applied in the gear design process and heat treatment practice. Moreover, more efforts and investigations are needed to reveal the mechanical and tribological properties of material: 14 Ni Cr 18 needs.

CHAPTER 1

INTRODUCTION

Designers face many problems during the design process of mechanical systems like performance, strength, life, wear, manufacturing considerations, maintainability, shape, cost, etc.

Failure problem is so highly affected factor of many design considerations that it must be studied and solved perfectly for the design success. One of the common parts in most mechanical systems is the gear box. Gear designers and manufacturers have to solve many problems through the design and manufacturing operations; one of those problems is the failure problems. The present work manipulates in details how to solve this problem by achieving, certain procedure to evaluate; the design, heat treatment, the mechanical & tribological properties, stress analysis, and manufacturing compared to standard recommendations.

1.1 DESIGN CONSIDERATIONS FOR GEARS

Many design considerations must be taken into account during the design of gears as; performance, strength, life, space, precision, noise, manufacturability, assemble ability, maintainability, cost, etc.

To verify those demands, gears must be optimally designed and manufactured for high performance depending on the geometry, accuracy, material selection and heat treatment. The design must follow the design rules of standards' specifications; as ISO, AGMA, DIN, etc.

Accuracy is obtained by selecting the efficient manufacturing operations and the production technique as hobbing, shaping, broaching, extruding, forming, powder sintering, etc.

Each production technique has its accuracy which may be suitable to some applications and not for others. So, the selection of gear production technique is important for verifying the design requirements.

1.2 GEAR FAILURE PROBLEMS

Failure can occur in gears due to many reasons such as; design errors, manufacturing errors, assembly errors and maintenance errors.

Failure due to design errors can be classified into performance analysis errors, geometrical analysis errors – Figure (1.1) shows the main nomenclatures of gears' geometries [1]- or manufacturing consideration errors. Performance analysis errors include strength, material and heat treatment specifications, which is carried out to increase the strength and the wear resistance of gear teeth.

The gear teeth wear is considered as one of the most important problems facing the designers and manufacturers of gear boxes. They have to reduce the effect of this phenomenon by engineering solutions.

Since the gear teeth are subjected to a high wear due to the sliding motion, pressure stress, fatigue stress and impact, the teeth surface must possess high wear resistance, whereas the core must be tough and strong enough to overcome the impact and the applied loads. Wear could be improved by controlling; hardness, lubricants, surface coatings, materials alloying elements.

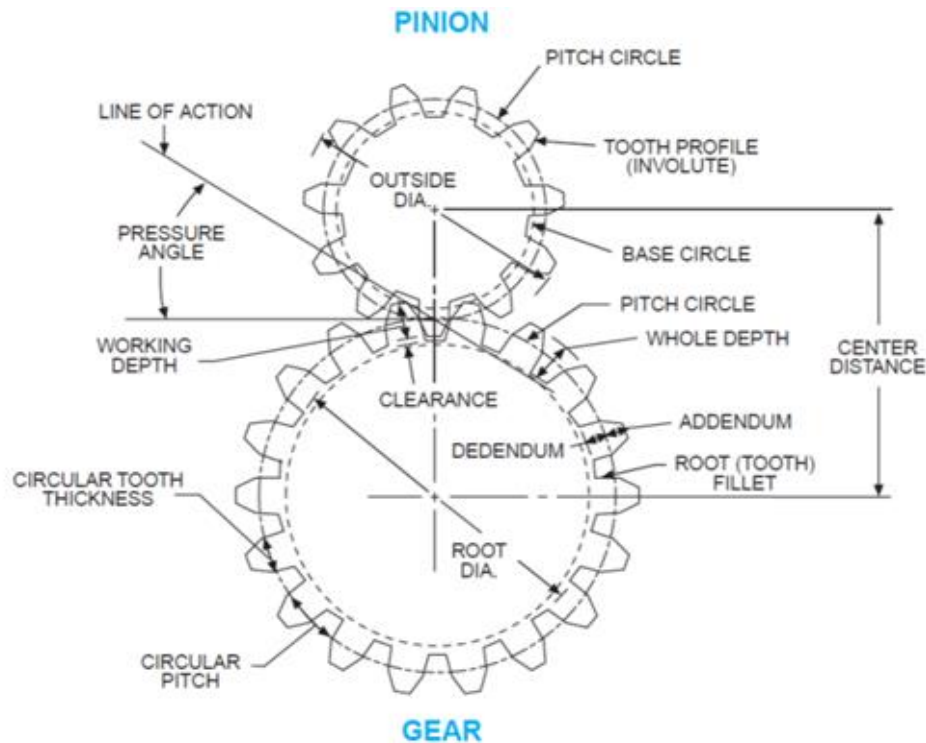


Fig. (1.1) Gear Geometry

1.3 GEAR MATERIALS

Material selection is one of the most important factor affecting the design of gears and performances. Material of gears must be selected depending on their applications (heavy, medium or light duty gears) and sizes. The ferrous base, copper base, polymeric base materials, etc. are used for various engineering gears applications.

Most of gears used in mechanical applications are ferrous base materials which are strong, tough and suitable to case hardening, such as 16MnCr5, 18Ni Cr Mo 7-6, 14 Ni Cr 18, etc. The common used material for good strength gears is DIN No (1.6587) (18Ni Cr Mo 7-6) and one of the high strength carburized gears materials is DIN No (1.5860) (14 Ni Cr 18), which has very high strength and recommended for heavy-duty gears.

1.4 HEAT TREATMENT

The mechanical and tribological properties of gear steel can be modified and improved by heat treatment operation. The gear material strength, toughness and wear resistance must satisfy the applications' requirements. For these reasons, the gear steel is heat treated to increase its strength, toughness and wear resistance. If the plain carbon steel is compared to alloy steel with the same hardness concerning strength, they are alike. But from the point of view of toughness and wear resistance, the alloy steel could be modified by heat treatment to give more strength, toughness and wear resistance. So, the alloy steels have a wide range of gear applications in the industry especially for precision applications. In the industry applications, the designers and manufacturers are using over 90% of the gears made from alloy steels [2]. Heat treatment of gear materials is classified into through hardening and case hardening. Case hardening is classified mainly to flame, induction, nitriding, boronizing, carburizing and mixing of some of those methods as carbonitriding. The famous three techniques of carburizing are gas, salt bath and solid beside other methods as plasma. Every technique has its characteristics and advantages.