Material Optimization of Gear and Pinion For Planetary Gearbox

Submitted By

Deepak Gupta

Kiran Phadatare

Abrar Shaikh

Mustafa Pawale

Symbol of Secularism & National Integration

DEPARTMENT OF MECHANICAL ENGINEERING

ANJUMAN-I-ISLAM

KALSEKAR TECHNICAL CAMPUS NEW PANVEL,

NAVI MUMBAI – 410206

UNIVERSITY OF MUMBAI

ACADEMIC YEAR 2014-2015

Project Report

On

Material Optimization of Gear and Pinion For Planetary Gearbox

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Deepak Gupta

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In partial fulfilment for the award of the Degree

Of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

UNDER THE GUIDANCE

Of

Prof. Altamash Ghazi

DEPARTMENT OF MECHANICAL ENGINEERING

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PLOT #2and3, SECTOR 16, NEAR THANA NAKA, KHANDAGAON, NEW PANVEL,NAVI MUMBAI-410206, Tel.: +91 22 27481247/48 * Website: www.aiktc.org

CERTIFICATE

This is to certify that the project entitled

"Material Optimization of Gear and Pinion for Planetary Gearbox"

Submitted by

Deepak Gupta

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Mustafa Pawale

To the Kalsekar Technical Campus, New Panvel is a record of bonafide work carried out by him under our supervision and guidance, for partial fulfilment of the requirements for the award of the Degree of Bachelor of Engineering in Mechanical Engineering as prescribed by **University Of Mumbai**, is approved.

Project co-guide	**Internal Examiner**	**External Examiner**
(Prof. Altamash Ghazi)	(Prof. Atul Meshram)	

Head of Department	**Principal**
(Prof. Zakir Ansari)	(Dr. A. R. Honnutagi)

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APPROVAL OF DISSERTATION

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In partial fulfilment of the requirements for the award of the Degree of Bachelor of Engineering in Mechanical Engineering, as prescribed by University of Mumbai approved.

(Internal Examiner) **(External Examiner)**

____________________ ____________________

Date: __________

Declaration

We declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, We have adequately cited and referred the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Name	Roll no	Signature
Deepak Gupta	11ME24	
Kiran Phadatare	11ME44	
Abrar Shaikh	11ME50	
Mustafa Pawale	11ME43	

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Patience and excellent expertise in discussion during progress of the project work have

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Deepak Gupta

Kiran Phadatare

Abrar Shaikh

Mustafa Pawale

Abstract

Gears are the important element of a mechanical system, which are used for variation of speed and power, failure of even a single tooth of a gear will make the machine to stop. Hence our aim is to strengthen the gear which is a key element of gear box. At Dynatech Engineering. Co. Ltd. due to catastrophic failure of gear teeth, the problem of gear teeth deformation occurred. Dynatech Engineering Co. needed to suggest appropriate gear material by considering its strength, cost, hardenability and machinability, due to past history of gear teeth failures. The materials utilized for pinion and gear are EN24 and EN8 respectively. The material properties and costing of pinion and gear material were studied, and standard gear materials were identified from PSG Design Data Book. The material sorting is done on the basis of availability, cost and strength of the material.

We studied different material selection methods like Weighted Point Method, TOPSIS, COPRAS, ELECTRA and VIKOR Method etc. From these methods Weighted Point Method (WPM) is selected for material selection and its result validated by TOPSIS Method and COPRAS Method. The material is selected by studying above method. On that material we did the finite element analysis and we also did analysis on currently used material in Dynatech Engineering co. The input parameter required for analysis provided by company such as module, teeth on pinion and gear, operating temperature and torque on which it is operating etc. The analysis is done by using the software ANSYS 15.0. From the result of it is concluded that the selected material have less deformation and stress during the operation at the top of the teeth as compare to the existing material.

Keywords: Gear, Material selection, PSG design data book, WPM, TOPSIS, COPRAS, ELECTRA, VIKOR, Analysis, Deformation, Stress.

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List of Abbreviations, Notations and Nomenclature

σ_u = Ultimate tensile stress .

σ_y= Yield stress.

δ_l = Elongation .

HB = Hardness.

AISI = American Iron and Steel Institute.

BS = British Standard.

IS = Indian Standard.

DBA = Distance based approach.

TOPSIS = Technique for order preference by similarity to ideal solution.

COPRAS = Complex proportional assessment.

ARAS = Additive ratio assessment.

ELECTRA = Elimination and choice expressing the reality.

Chapter 1

Introduction

1.1 Selection of Project

We were interested in getting an industrial project, so we searched few companies in MIDC, Taloja. Hence we got industrial project at Dynatech Engineering. Co. on Material Optimization of Gear And Pinion For Planetary Gear Box.

1.2 Introduction of Company

We got this industrial project from Dynatech Engineering Company.

This Company is located at Taloja MIDC.

They manufacture the following component:-

- Special Ultra Planetary Gearbox
- Mixing System
- Double Cone Vacuum Dryer
- Tray/Vacuum Tray Dryer
- Rotary Tunnel Dryer
- Agitated Pressure /Vacuum Filter
- Distillation Unit

1.3 Problem Definition:

Recently Dynatech Engineering Co. has supplied a planetary gearbox to few of their customers. Within two months of its use teeth of gear had broken. To remove this problem they increase the hardness of the gear before machining in first case and after machining in second case. But both cases were failed and gear dimensions got altered. So, they decided to search for new appropriate material to resolve this problem.

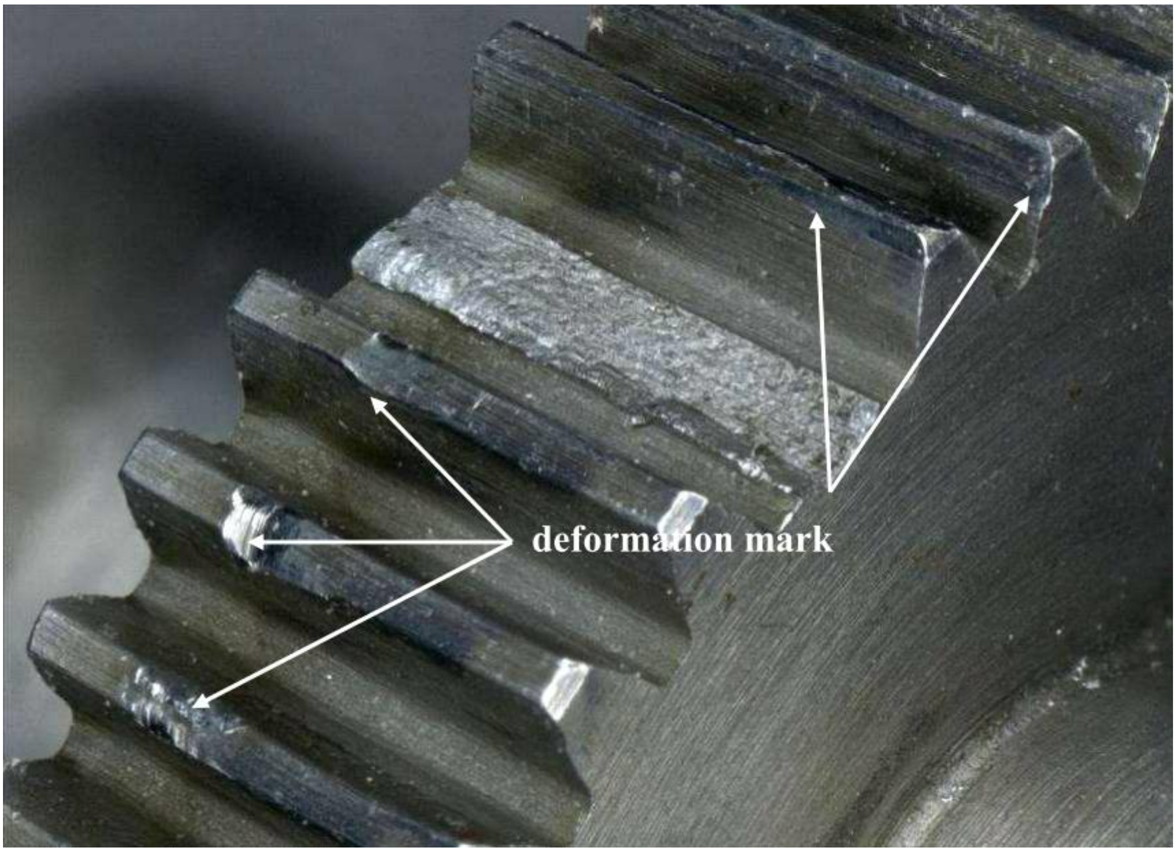

Figure 1 Gear teeth deformation

1.4 Introduction of Gears

A Gear can be defined as the mechanical element used for transmitting power and rotary motion from one shaft to another by means of progressive engagement of projections called teeth. Spur Gears use no intermediate link or connector and transmit the motion by direct contact. The two bodies have either a rolling or a sliding motion along the tangent at the point of contact. No motion is possible along the common normal as that will either break the contact or one body will tend to penetrate into the other. Thus, the load application is gradual which results in low impact stresses and reduction in noise. Therefore, the spur gears are used in transmitting power with very less friction losses. [2]

1.4.1 Gears

Imagine two disks are placed side by side, tangent to each other (both touching), if one disk was rotated, due to friction (caused by surface roughness) the other disk would also rotate (in the opposite direction) however; slippage would be introduced due to variation in the surface roughness. Now if we were to increase that surface roughness by cutting the disks and forming teeth on the circumference (circular outer part) then slippage would be eliminated. As a result, we would have one of the most important fundamental mechanical devices, which can manipulate speed, torque and rotational axis. Almost all machines that involve rotation have gears. Gears are found in everything from cars to clocks. [2]

1.4.2 Requirement of gear:

Gears have neat characteristics which aid in the development of complex machineries: Gears can transmit power with very less friction loss. Gears can reverse the direction of rotation. It can change the speed or torque (turning force) of rotation. It can transfer rotation to a different axis or translate rotational into linear motion or vice versa. [2]

1.4.3 Classification of Gears:

The basic classification of gears includes the following types, they are

Spur gear

Helical gear

Worm gear etc. [2]

1.4.4 Gear material

Gears are made of cast iron, steel, bronze and phenolic resins. Large size gears are made of grey cast iron of Grades FG 200, FG 260 or FG 350. They are cheap and generate less noise compared with steel gears. They have good wear resistance. Their main drawback is poor strength. Case- hardened steel gears offer the best combination of a wear-resisting hard surface together with a ductile and shock- absorbing core. The plain carbon steels used for medium duty applications are 50C8, 45C8, 50C4 and 55C8. For heavy duty applications , alloy steels 40Cr1 ,30Ni4Cr1 and 40Ni3Cr651 and 40Ni3Cr65Mo55 are used. For planetary gear trains, alloy steel 35Ni1Cr60 is recommended. Although steel gears are costly, they have higher load carrying capacity. Bronze is mainly used for worm wheels due to its low coefficient of friction and excellent conformability. It is also suitable where resistance to corrosion is an important consideration in applications like water pumps.

In non- metallic gear drives, only the pinion is made of non- metals such as moulded nylon, laminated phenolics like Bakelite or Cerolon. They can tolerate errors in the tooth profile.[2]

1.5 Planetary Gearbox

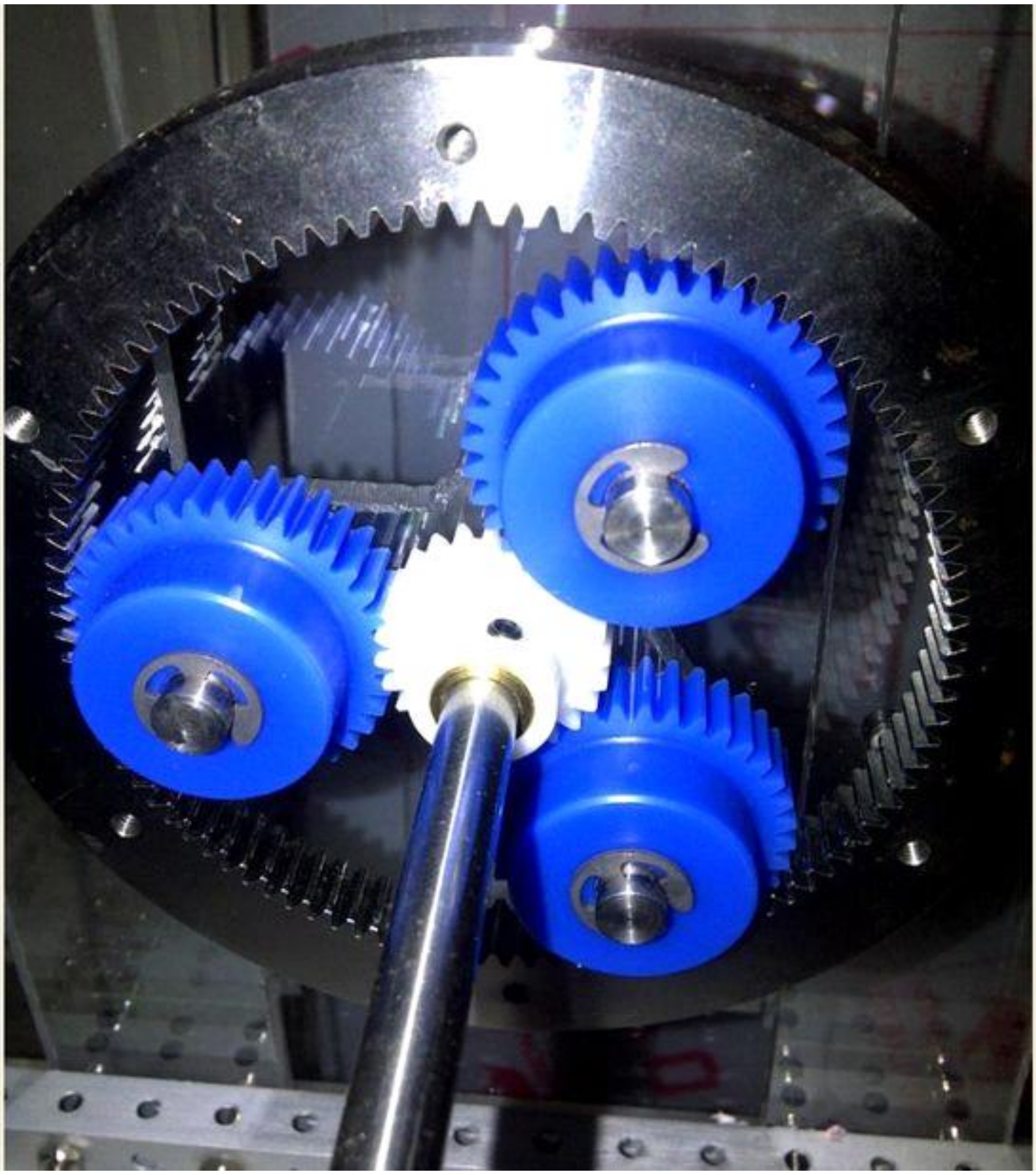

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Figure 2 Planetary gear box

Planetary gear box works on planetary motion principle each stage of the planetary gear box consists of a central Sun Gear meshing with accurately positioned three Planet Gears around it which in turn mesh with the internal teeth of the outer Ring Gear. Normally, the Ring gear is stationary and forms the part of the housing, input is given to the sun gear and output is derived from the three planet gears through a planet carrier. [11].

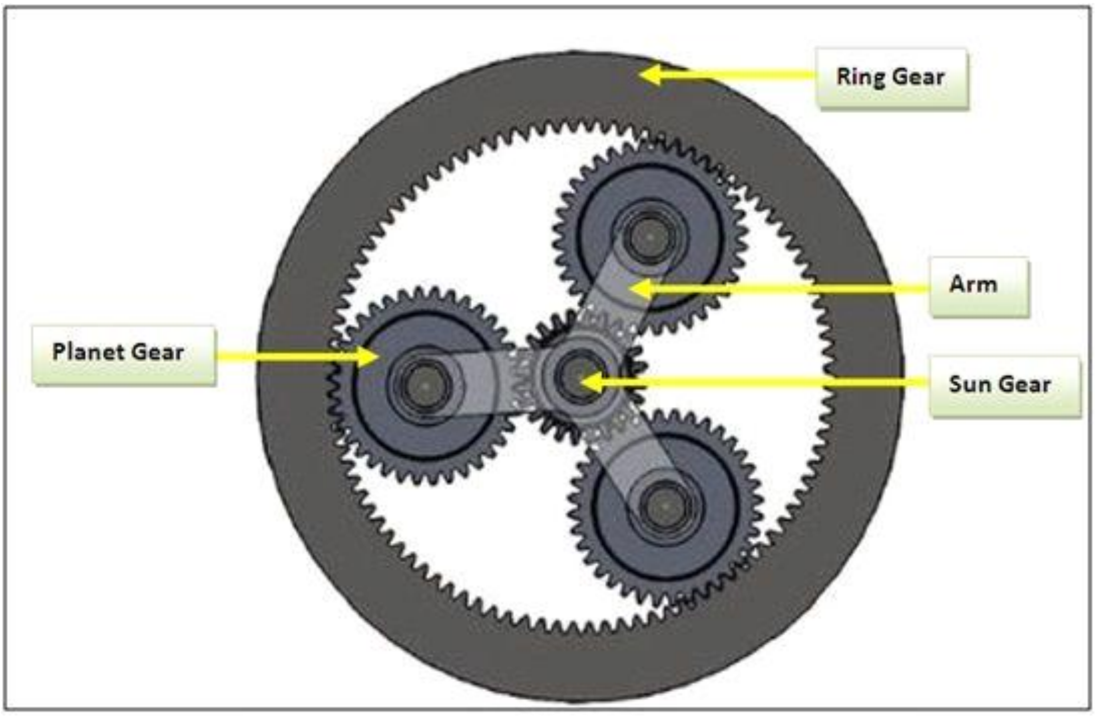

Figure 3 Planetary gear box

1.5.1 Working of Planetary Gear set:

- Any one of the three members can be used as the driving or input member
- At the same time, another member might be kept from rotating and thus becomes the reaction, held, or stationary member.
- The third member then becomes the driven or output member.
- Output direction can be reversed through various combinations [11].

1.5.2 Advantages of Planetary gearbox:

- Compared to conventional gearbox has smaller dimensions.
- Easier to sort through the constant rounds of shot.
- Greater durability than conventional bikes in gear.
- Easy to achieve high transmissions ratio due to the size. [11]

1.5.3 Disadvantages of Planetary gearbox:

- More expensive than conventional production of gearboxes.
- More complex than conventional transmissions. [11]

1.5.4Special Features of Planetary gearbox

- All shafts are made of special alloy steel and are hardened and tempered.
- Good quality bearings for input and output shafts.
- High efficiency.
- Low noise level.
- No oil leakages.
- Taper roller bearings on output shafts for bigger models.
- Long and trouble free performance. [11]

Chapter 2

Literature review

Literature Review

Ali Jahan and K.l.Edward has proposed the concept of VIKOR method for material selection problem with interval numbers and target based criteria. The problem with supporting decision-making to help choose materials in engineering design is that it needs different tools in different situations. This is because there is actually a range of values for any property of a given material and there are several methods in multi-attribute decision making (MADM) for ranking of alternatives based on interval data. Recently some MADM methods have been updated for materials selection that address target-based criteria, and validated using biomedical implant design applications. When data are not exact and target-based criteria available, the current methods must be modified to show the correct ranking of materials. Therefore, in this research a new VIKOR method for ranking materials with simultaneous availability of interval data and all types of criteria is presented.

Three practical examples of materials selection, including biomedical implants, are presented to demonstrate the extended approach and its validity. It is shown that when there are no target criteria, the new method is the same as the conventional method.[6]

Mohammed F. Aly, Hazem A. Attia and Ayman M. Mohammed has explained TOPSIS model for best design concept and material selection process. An extension of TOPSIS, a multi-attribute decision making (MADM) technique, to a group decision environment is investigated. TOPSIS is a practical and useful technique for ranking and selection of a number of externally determined alternatives through distance measures. The entropy method is often used for assessing weights in the TOPSIS method. Entropy in information theory is a criterion uses for measuring the amount of disorder represented by a discrete probability distribution. According to decrease resistance degree of employees opposite of implementing a new strategy, it seems necessary to spot all managers' opinion. The normal distribution considered the most prominent probability distribution in statistics is used to normalize gathered data. [10]

Rahul Malik, R.K. Garg and S.K. Jarial has explained the optimal selection of gear material by using DBA method. A deterministic quantitative model based on Distance Based Approach (DBA) method has been developed for evaluation, selection and ranking of gear materials, which is a concept hitherto not employed in selection problem of this kind. As a significant development over and above past approaches to gear materials selection, it recognizes the need for, and processes the information about, relative importance of attributes for a given application, without which inter-se-attribute comparison could not be accomplished. It successfully presents the results of this information processing in terms of a merit value which is used to rank the gear materials. In order to demonstrate the aptness of using DBA method as a decision aid, the results so obtained have been compared with other techniques and methods available in the open literature.[3]

Prasenjit Chatterjee and Shankar Chakraborty has explained the COPRAS and ARAS method. Material selection is one of the most important decisions in optimal design of any manufacturing process and product. Proper material selection plays an elementary role for a productive manufacturing system with superior product and process excellence along with cost optimization. Improper material selection frequently causes enormous cost contribution and drives an organization towards immature product failure. A proficient methodology for material selection is thus required to help the manufacturing organizations for selecting the best material for a particular application. This paper focuses on the applications of two almost unrevealed multi-criteria approaches, namely complex proportional assessment (COPRAS) and additive ratio assessment (ARAS)-based methods for solving a gear material selection problem in a given manufacturing environment. A complete list of all the prospective materials from the best to the worst is obtained, taking into account multi-conflicting material selection attributes. The ranking performance of these two methods is also compared with that of the past researchers.[5]

Radinko Gligorijevic, Jeremija Jevtic, Djuro Borak has explained Material selection and gear design. Materials and process selection are key issues in optimal design of industrial products. Substituting and selecting materials for different machining parts is relatively common and often. Material selection is a difficult and subtle task, due to the immense number of different available materials. From this point of view paper deal with a set of major gear design criteria which are used for gear material selection. The main gear design criteria are: surface fatigue limit index, bending fatigue limit index, surface fatigue lifetime index, bending fatigue lifetime index, wear resistance of toots flank index and machinability index. Using computer allows a large amount of information to be treated rapidly. One the most suitable model, for ranking alternatives gear materials, is ELECTRA, which using a multiple criteria, which all material performance indices and their uncertainties are accounted for simultaneously.[4]

Chapter 3

Report on present investigation

3.1 Parameters considered for material selection

3.1.1 Mechanical Properties:

Mechanical properties are the most important technical factor governing the selection of material. They include strength under static and fluctuating loads, elasticity, plasticity, stiffness, resilience, toughness, ductility, malleability and hardness. Depending upon the service conditions and the functional requirement, different mechanical properties are considered and a suitable material is selected.[2]

3.1.2 Manufacturing Considerations:

In some application, machinability of material is an important consideration in selection. Free cutting steels have excellent machinability, which is an important factor in their selection for high strength bolts, axles and shaft.[2]

3.1.3 Availability:

The material should be readily available in the market, in large enough quantities to meet the requirement. Cast iron and aluminium alloy are always available in abundance while shortage of lead and copper alloys is common experience.[2]

3.1.4 Cost:

For every application, there is a limiting cost beyond which designer cannot go. When this limit is exceeded, the designer has to consider other alternative materials. In cost analysis, there are two factors, namely, cost of material and the cost of processing the material into finished goods.[2]

3.2 Expected material optimization methods:

Weighted Point Method

WPM is based on comparison of GO/NO- GO properties and discriminating properties of materials. [2]

TOPSIS

TOPSIS is based on the concept of that the chosen alternative should have the shortest geometric distance from the positive ideal solution and longest geometric distance from the negative ideal solution. [11]

COPRAS

COPRAS is based on the concept of listing of all the prospective materials from the best to the worst, taking into account multi conflicting material selection attributes. [5]

VIKOR

VIKOR ranks alternatives and determines the solution named compromise that is the closest to the ideal. [6]

DBA

DBA is based on matrix operations which can be easily computed using MATLAB. The DBA method is validities by comparing results of ranking with TOPSIS method. [3]

ELECTRA

One of the most suitable model is ELECTRA which using a multiple criteria where all material performance indices and their uncertainties are accounted for simultaneously. [4]

3.3 Selected material optimization method:

- Weighted Point Method.
- TOPSIS.
- COPRAS.

3.4 Properties of currently used material in Dynatech co.:-

1) Properties of EN24 Material:-

BS 970:1955 = EN24 (Pinion)

AISI = 4340

IS = 40Ni2cr1Mo28

Table 1 Chemical composition (in %)

C	SI	Mn	S	P	Cr	Mo	Ni
0.36-0.44	0.1-0.35	0.45-0.7	0.04 max	0.035	1-1.4	0.2-0.35	1.3-1.5

Table 2 Mechanical properties

Tensile Stress (N/mm^2)	Yield Stress (N/mm^2)	Elongation (%)	Izod Impact	Hardness (HB)
850-1000	680 (min)	13	54	248-300

2) Properties of EN8 material:-

BS = En8 (Gear)

AISI = 1040

IS = C45

able 3 Chemical composition:-

% C	% Mn
0.4-0.5	0.6-0.9

Table 4 Mechanical properties:-

Tensile Stress (N/mm^2)	Yield Stress (N/mm^2)	Elongation (%)	Izod Impact	Hardness (HB)
630-710	360	15	41	230

3.5Properties of suggest new material at Dynatech co.:-

1) Properties of EN30A Material:-

BS 970:1955 = EN30A (Pinion)

IS = 30Ni4Cr1

Table 5 Chemical composition:-

%C	%Si	%Mn	%Ni	%Cr	%Mn
0.26-0.34	0.1-.35	0..47-0.7	3.9-4.3	1.1-1.4	0.1-0.25

Table 6 Mechanical properties:-

Tensile Stress (N/mm$^{2)}$	Yield Stress (N/mm$^{2)}$	Elongation (%)	Izod Impact (N/m)	Hardness (HB)
1550	1300	8	140	444 min

3.6 Application of materials

Uses of EN24 material:-

High strength machine parts like collets, spindles, bolts, gear etc. [1]

Uses of EN8 material:-

Steel for Spindle of machine tool, gear, blots and shaft. [1]

Uses EN30A material:-

Used for making highly stressed gears and other components requiring high surface hardness Of the order 160 Kgf/mm^2 and where minimum distortion in heat treatment is essential. [1]

Chapter 4

Ranking methods

4.1 Weighted Point Method:

The material selection process needs systematic and analytical approach. The weighted point method is one of the commonly used methods for the material selection.

1. Desirable properties for the gear application

GO/NO-GO properties

1) Machinability (M)

2) Availability (A)

3) Hardenability (H)

4) Toughness (T)

Discriminating properties

1) Ultimate tensile stress (σ_u)

2) Yield stress (σ_u

3) Elongation (δ l)

4) Hardness (HB)

5) Cost in Rs.

Table 7 Standard Gear Materials

B.S.	Material	σ_u (N/mm^2)	σ_u (N/mm^2)	δ l (mm)	HB	Cost(Rs)
EN24	40NiCr1Mo28	950	600	16	277	80
EN8	C45	710	360	15	229	80
EN9	C55Mn75	780	460	15	255	67
EN18	40Cr1	850	540	18	248	------
EN111	35Ni1Cr60	850	540	18	248	80
EN30A	30Ni4Cr1	1550	1300	8	444 min	67

2. Weighting factor ‘W’ for discriminating properties (Prop.)

Positive Decision (Pi)

Weighting Factor (Wi = Pi/∑Pi)

Table 8 Weighting Factor

Prop.	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5	Pi	Wi
S_u	1	1	1	1							4	0.4
S_y	0				1	0	0				1	0.1
δ l		0			0			0	1		1	0.1
HB			0			1		1		1	3	0.3
Cost				0			1		0	0	1	0.1

3. Material selection chart

Table 9 Material selection chart

Material	Go/No-Go properties				σy W1=0.4		σ_u W2=0.1		δ l W3=0.1		HB W4=0.3		Cost W5=0.1		Material Performance Index Y=∑BiWi
	M	A	H	T	B1	B1W1	B2	B2W2	B3	B3W3	B4	B4W4	B5	B5W5	
EN24	Y	Y	Y	Y	61.3	24.52	46.1	4.61	88.9	8.89	62.4	18.7	83.7	8.37	65.12
EN8	Y	Y	Y	Y	45.8	18.32	27.7	2.76	83.3	8.33	51.6	15.4	83.7	8.37	53.27
EN9	Y	Y	Y	Y	50.3	20.13	35.3	3.53	83.3	8.33	57.4	17.23	100	10	59.23
EN111	Y	Y	Y	Y	54.8	21.9	41.5	4.15	100	10	55.1	16.7	83.7	8.37	61.23
EN325	Y	N	Y	Y	--	--	--	--	--	--	--	--	--	--	--
EN30A	Y	Y	Y	Y	100	40	100	10	44.4	4.44	100	30	100	10	95.4
EN18	Y	N	Y	Y	--	--	--	--	--	--	--	--	--	--	--

4. Selection of material

The material selected is EN30A with material performance index of 94.44.

4.2 COPRAS Method:

Table 10 Standard gear materials

Materials	σu	$\sum$y	δ l	HB	Cost (Rs/kg)
EN24	980	600	16	277	80
EN8	710	360	15	229	80
EN9	780	460	15	225	67
EN18	850	540	18	248	-
EN111	850	540	18	248	80
EN325	--	--	--	--	--
EN30A	1500	1300	8	494	67

To calculate the ranks of the properties of different materials we use the following formula.

$$Yi = 1+\frac{(Xi-A)(N-1)}{(B-A)}$$

Xi = Property value.

A = Minimum value of property.

B =Maximum value of property.

N =No.of properties.

By using the ranks obtained from above formula we will calculate the weights of all the properties of given materials.

Table 11 Weights of all the properties of given materials

Materials	σu	$\sum$y	HB	Cost(Rs/kg)	Δl
EN24	0.0574	0.0486	0.058	0.0508	0.0364
EN8	0.0429	0.0291	0.0479	0.0508	0.03416
EN9	0.0472	0.0372	0.05019	0.0425	0.03416
EN18	0.0514	0.0437	0.0519	-	0.041
EN111	0.0514	0.0437	0.1034	0.0508	0.041
EN30A	0.0937	0.1053	0.0534	0.0425	0.0182

By comparing the above properties of each material, we select σu, σy, cost and HB as beneficial properties(S+i) and δl as unbeneficial property(S-i).

Table 12 beneficial properties(S+i) and unbeneficial properties (S-i)

S+1 = 0.2148	S-1 = 0.0364
S+2 = 0.1707	S-2 = 0.03416
S+3 = 0.1803	S-3 = 0.03416
S+4 = 0.147	S-4 = 0.041
S+5 = 0.1978	S-5 = 0.041
S+6 = 0.3449	S-6 = 0.0182
∑S+i =1.255	∑S-i =0.2049

S-min /S-i

Table 13 S-min /S-i

S-1 = 0.5
S-2 = 0.5327
S-3 = 0.5237
S-4 = 0.444
S-5 = 0.444
S-6 = 1
∑S-i =3.4534

$$Qi = Si + \frac{\sum_{i=1}^{m} \text{S}-\text{i}}{\sum_{i=1}^{m} (\text{s}-\text{min})/(\text{s}-\text{i})}$$

By Formula for Q, we have

Table 14 Value of Q

Q = 0.244
Q = 0.2033
Q = 0.212
Q = 0.1733
Q = 0.224
Q = 0.4042

Utility factor formula

U = (Qi /Qmax) x 100

Table 15 Utility factor

U = 60.46 %
U = 50.0 %
U = 52.45 %
U = 42.87 %
U = 55.42 %
U =100 %

Rank of materials according to COPRAS method is as follow:

Table 16 Rank of materials

EN24	2
EN8	5
EN9	4
EN18	6
EN111	3
EN30A	1

4.3 TOPSIS Method:

Step1:-Create Matrix

Table 17 Standard gear materials

Material	σu	$\sum$y	δ l	HB	Cost
EN24	950	600	16	277	80
EN8	710	360	15	229	80
EN9	780	460	15	255	67
EN111	850	540	18	248	80
EN30A	1550	1300	8	444	67

Step2:-Normalize

rij=(xij/√sum(x×x)ij)

Table 18 Normalize

Material	σu	$\sum$y	δ l	HB	Cost
EN24	0.42	0.36	0.48	0.41	0.48
EN8	0.31	0.22	0.45	0.34	0.48
	0.34	0.28	0.45	0.38	0.4
EN111	0.37	0.33	0.54	0.37	0.48
EN30A	0.68	0.79	0.24	0.66	0.4

Step3:-Weighted normalized decision matrix

wi=(Wj/sum of Wj)

Table 19 Weighted normalized decision matrix

Material	σu		σy		Δl		HB		Cost	
	W.	w	W.	w	W.	W	W.	W	W.	W
EN24	4.	0.27	4.	0.27	4.	0.27	4.	0.27	3.	0.2
EN8	1.	0.07	1.	0.07	2.	0.13	1.	0.13	1.	0.07
EN9	2.	0.13	2.	0.13	3.	0.2	3.	0.2	4.	0.27
EN111	3.	0.2	3.	0.2	5.	0.33	2.	0.33	2.	0.13
EN30A	5.	0.33	5.	0.33	1.	0.07	5.	0.07	5.	0.33

tij= (Wi*rij)

Table 20 Values of tij

	σ_u	σ_y	Δl	HB	Cost
EN24	0.1134	0.099	0.1306	0.1107	0.096
EN8	0.02192	0.0154	0.05895	0.024	0.0336
EN9	0.0447	0.0365	0.0907	0.076	0.108
EN111	0.075	0.06594	0.1796	0.05	0.0624
EN30A	0.2256	0.2619	0.0169	0.2177	0.132

Step 4: Calculate the distance between alternate 'I' and worst condition,

Alternate 'I' and best condition

$d_{iw} = \sqrt{\sum_{J=1}^{N}(tij - twj)^2}$

$d_{ib} = " \sqrt{\sum_{J=1}^{N}(tij - tbj)^2}$

Table 21 distance value

	d_{iw}	d_{ib}
EN24	0.04153	0.054
EN8	0.04842	0.0716
EN9	0.098	0.1022
EN111	0.1332	0.2332
EN30A	0.03936	0.2696

Step 5:Calculate similarity to worst condition

$S_{iw} = \frac{diw}{diw+dib}$

Table 22 similarity to worst condition

	S_{iw}	Rank
EN24	0.4347	3
EN8	0.4034	4
EN9	0.4904	2
EN111	0.3641	5
EN30A	0.5944	1

Chapter 5

Finite Element Analysis

5.1 Finite Element Analysis

The finite element method is numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in almost every industry.
In more and more engineering situations today, we find that it is necessary to obtain approximate solutions to problem rather than exact closed form solution. It is not possible to obtain analytical mathematical solutions for many engineering problems. An analytical solutions is a mathematical expression that gives the values of the desired unknown quantity at any location in the body, as consequence it is valid for infinite number of location in the body.
For problem involving complex material properties and boundary conditions, The engineer resorts to numerical methods that provide approximate, but acceptable solutions. The finite element method has become a powerful tool for the numerical solutions of a wide range of engineering problems. It has been developed simultaneously with the increasing use of the high- speed electronic digital computers and with the growing emphasis on numerical methods for engineering analysis. This method started as a generalization of the structural idea to some problems of elastic continuum problem, started in terms of different equations.

5.2 FEA Software

There are different software available for FEA some of them are:
_ ALTAIR HYPER WORKS
_ ANSYS
_ NASTRAN
_ COSMOS
_ LS –DYNA
ANSYS is used as the FEA tool

5.2.1 ANSYS

ANSYS is an engineering simulation software provider founded by software engineer John Swanson. It develops general-purpose finite element analysis and computational fluid dynamics software. While ANSYS has developed a range of computer-aided engineering (CAE) products, it is perhaps best known for its ANSYS Mechanical and ANSYS Multiphysics products. ANSYS Mechanical and ANSYS Multiphysics software are non exportable analysis tools incorporating pre-processing (geometry creation, meshing), solver and post-processing modules in a graphical
user interface. These are general-purpose finite element modelling packages for numerically solving mechanical problems, including static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems.

5.3 Analyzing the Model – Step By Step Procedure

_ The 3D model of the gear is converted as **IGES** format through the PRO-E software
_ The **IGES** (**I**nitial **G**raphic **E**xchange **S**ystem) format is suitable to import in the ANSYS Workbench for analyzing
_ open the ANSYS workbench

_ Create new geometry

_ File – import external geometry file – generate
_ Project – new mesh
_ Defaults – physical preference – mechanical
_ Advanced – relevance centre – fine
_ Advanced – element size – 0 mm
_ Right click the mesh in tree view – generate mesh
_ Project – convert to simulation – yes
_ Select the solid in geometry tree
_ Definition – material – import – work bench samples – select carbon steel and stainless steel – ok
_ New analysis – static structural
_ Static structural – right click – insert – fixed support
_ Select the face
_ Geometry – apply
_ Static structural – right click – insert – force
_ Geometry – app
_ Magnitude – N
_ Static structural – right click – insert – moment
_ Geometry – apply
_ Magnitude –N/mm
_ Static structural – right click – insert –rotational velocity
_ Geometry – apply
_ Magnitude –RPM
_ Solution – insert the total deformation and equivalent stress.
_ Right click the solution icon in the tree – solve
_ After solve the analysis – take the reading of above mentioned items.
_ The all results are taken in a picture – and save it to the required folder in the system
_ The all readings are tabulated. [9]

5.3.1 Input parameters for ANSYS

Case 1:

EN30A material for pinion and EN24 material for gear.

Case 2:

EN 24 material for pinion and EN 8 material for gear (currently used materials in industry)

Moment= 100 Nm

Module= 8 mm

Teeth on pinion= 17

Teeth on gear= 68

Environmental Temperature= $32^{o}C$

5.4 Snapshots

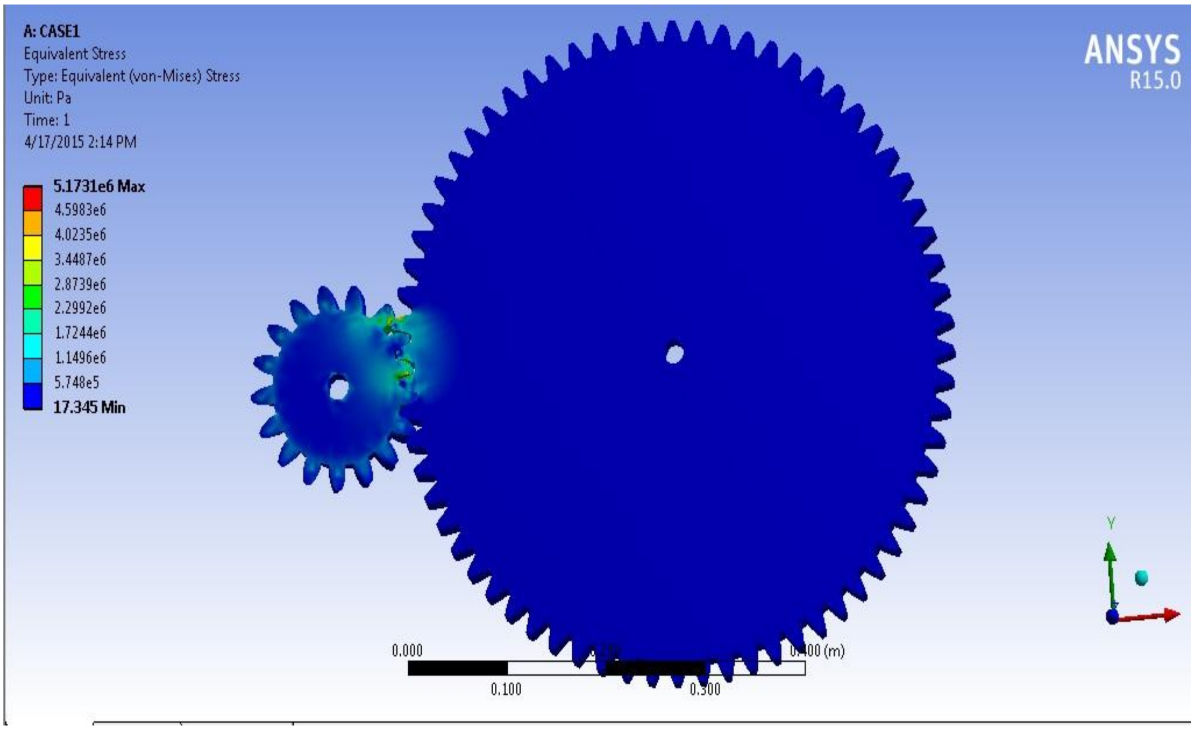

Figure 4 Equivalent stress of case 1

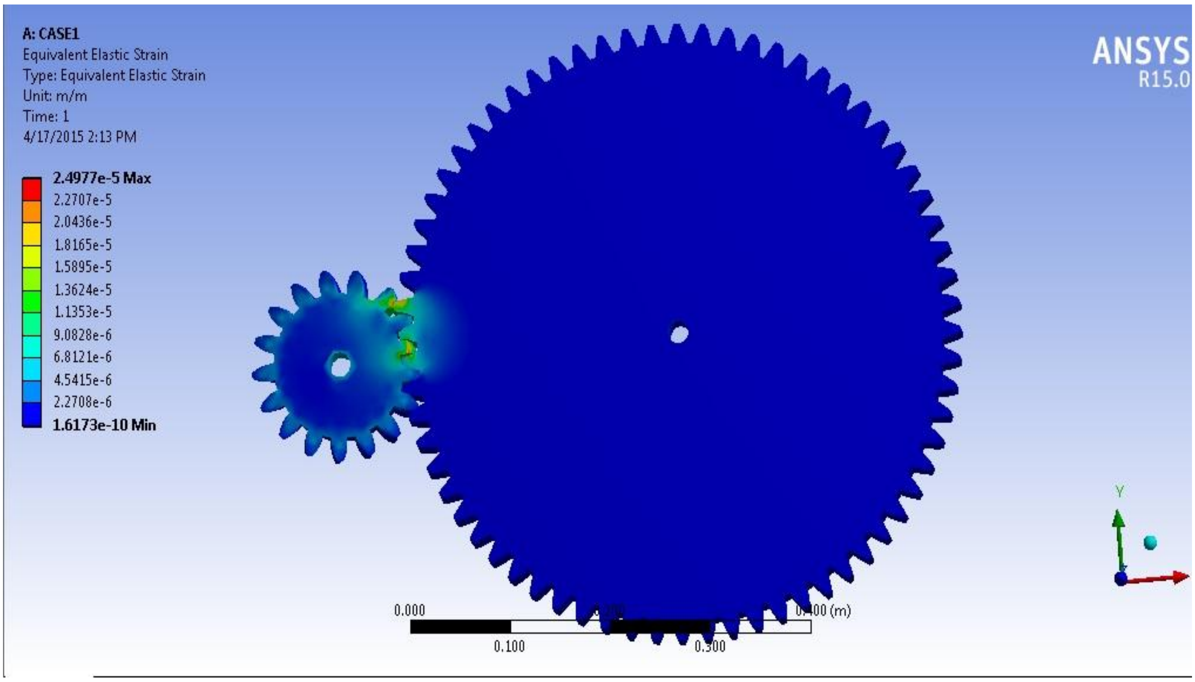

Figure 5 Equivalent elastic strain of case 1

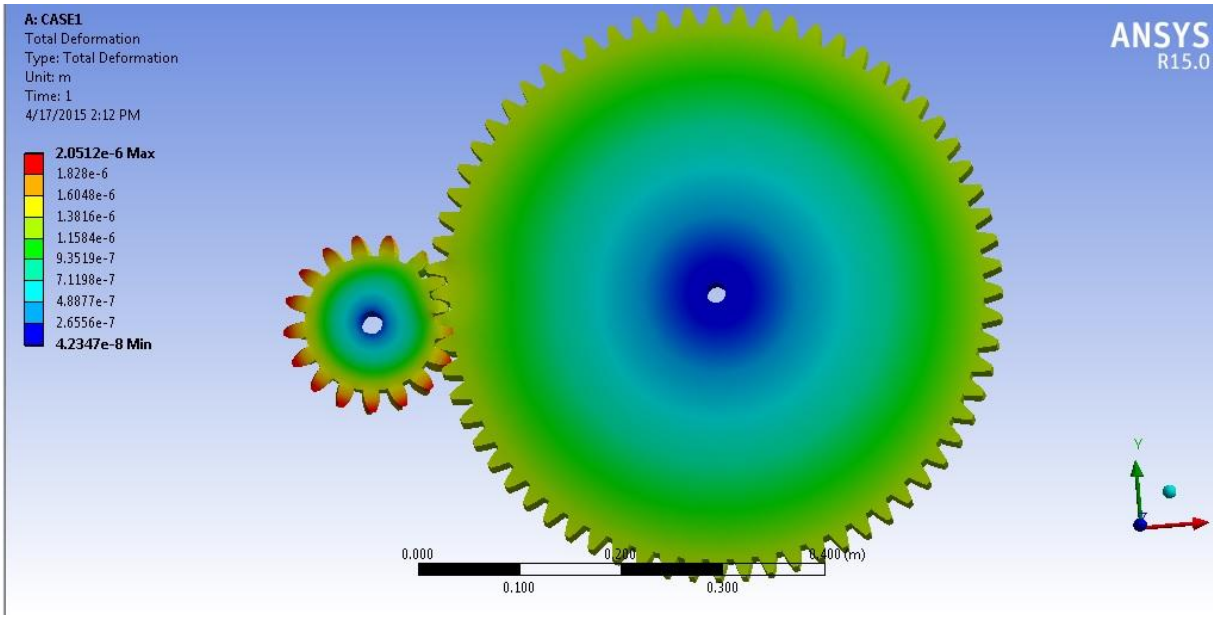

Figure 6Total deformation of case1

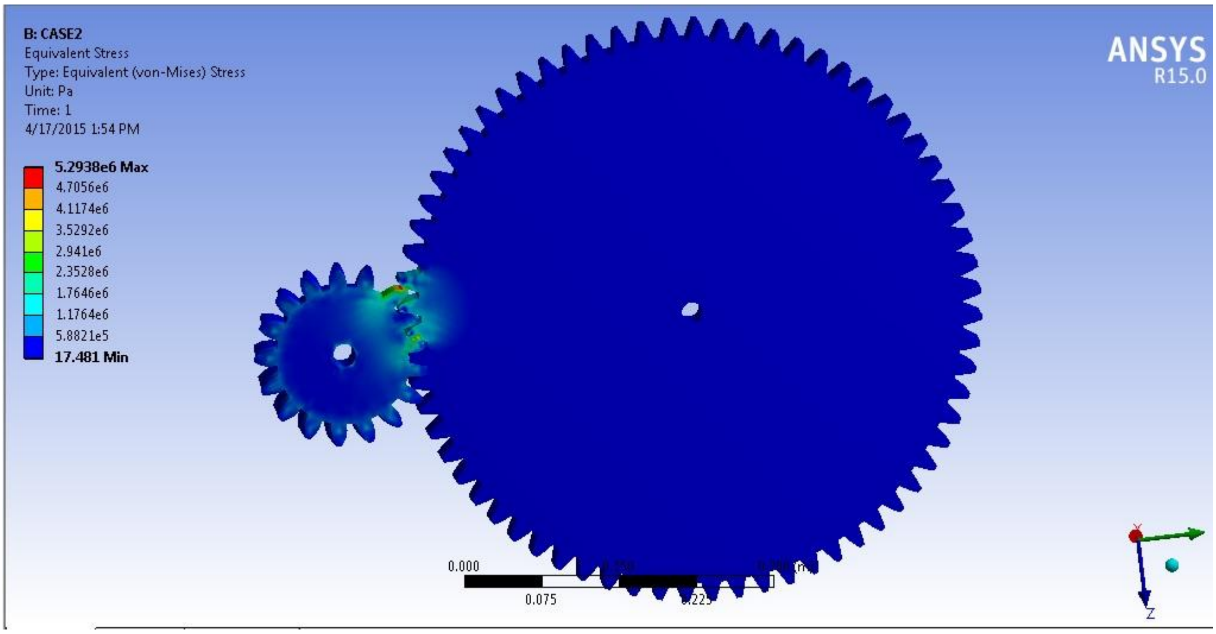

Figure 7 Equivalent stress of case 2

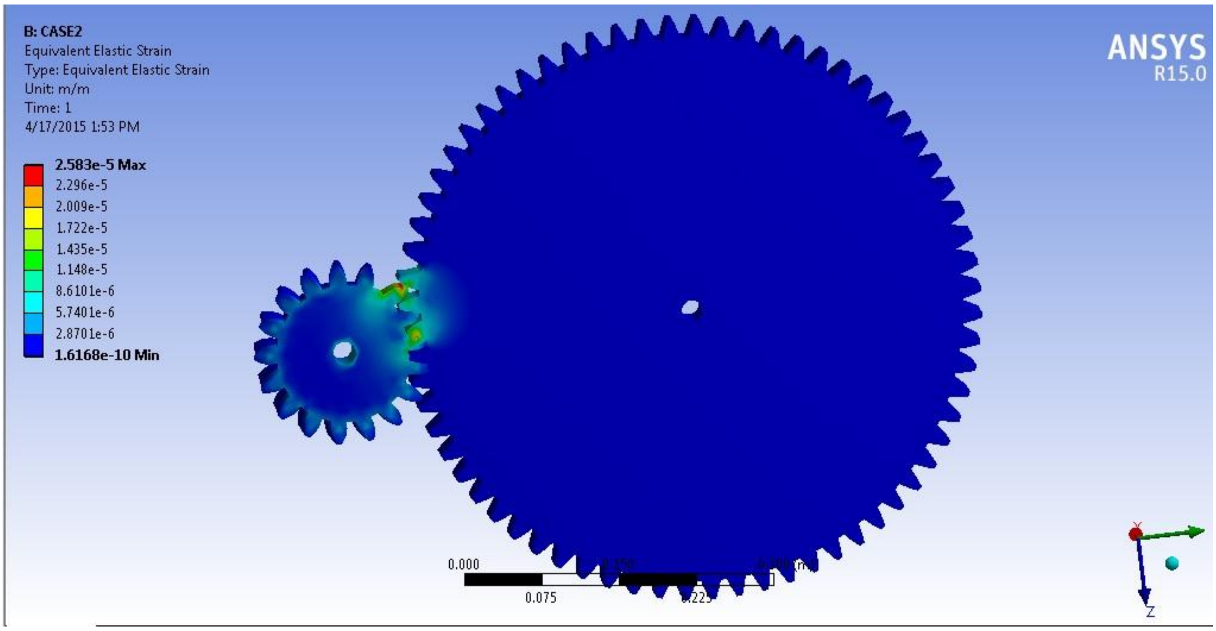

Figure 8 Equivalent elastic strain of case 2

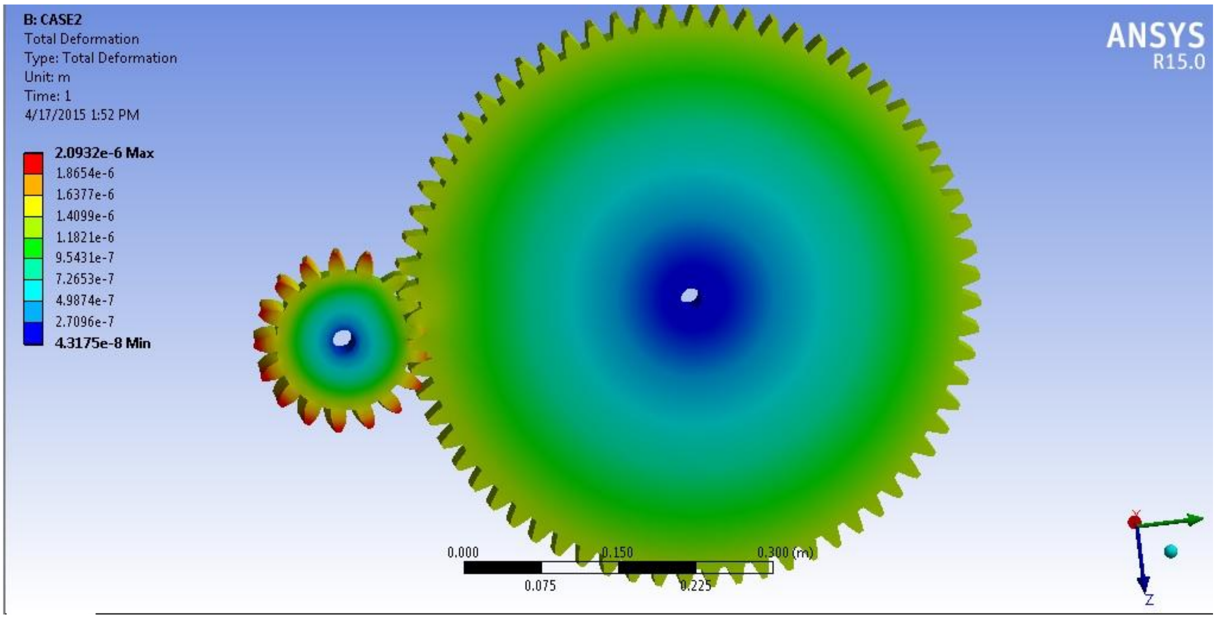

Figure 9 Total deformation of case 2

Chapter 6

Results and discussions

6.1 Comparison of ranking of material by various method:

Table 23Result of ranking method

Material	Ranking By WPM	Ranking by COPRAS	Ranking by TOPSIS
EN24	2	2	3
EN8	5	5	4
EN9	4	4	2
EN111	3	3	5
EN30A	1	1	1

6.1.1 Comment on result of ranking method

1) By studying above methods, we conclude that EN 30A material has got first priority and EN 24 material has got second priority as per WPM and COPRAS method
2) As per the TOPSIS method, EN 30A material got first priority and EN 24 material got second priority.

6.2 ANSYS result for case 1

Table 24
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done

Table 25
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

Table 26
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Equivalent Elastic Strain*	*Equivalent Stress*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Results			
Minimum	4.2347e-008 m	1.6173e-010 m/m	17.345 Pa
Maximum	2.0512e-006 m	2.4977e-005 m/m	5.1731e+006 Pa
Minimum Occurs On	Solid		
Maximum Occurs On	Solid		
Minimum Value Over Time			
Minimum	4.2347e-008 m	1.6173e-010 m/m	17.345 Pa
Maximum	4.2347e-008 m	1.6173e-010 m/m	17.345 Pa
Maximum Value Over Time			
Minimum	2.0512e-006 m	2.4977e-005 m/m	5.1731e+006 Pa

Maximum	2.0512e-006 m	2.4977e-005 m/m	5.1731e+006 Pa
Information			
Time	10^6 cycles		
Load Step	1		
Substep	1		
Iteration Number	1		
Integration Point Results			
Display Option		Averaged	
Average Across Bodies		No	

Material Data

EN24

Table 27
EN24 > Constants

Density	7850 kg m^-3

Table 28
EN24 > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.05e+011	0.29	1.627e+011	7.9457e+010

Table 29
EN24 > Tensile Yield Strength

Tensile Yield Strength Pa
5.9059e+008

Table 30
EN24 > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
8.2e+008

EN30A

Table 31
EN30A > Constants

Density	7800 kg m^-3

Table 32
EN30A > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.1e+011	0.28	1.5909e+011	8.2031e+010

Table 33
EN30A > Tensile Yield Strength

Tensile Yield Strength Pa
2.9559e+008

Table 34
EN30A > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
5.2e+008

6.3 ANSYS result for case 2

Table 35Model (B4) > Static Structural (B5) > Solution

Object Name	*Solution (B6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	**Done**

Table 36
Model (B4) > Static Structural (B5) > Solution (B6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

Table 37
Model (B4) > Static Structural (B5) > Solution (B6) > Results

Object Name	*Total Deformation*	*Equivalent Elastic Strain*	*Equivalent Stress*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Results			
Minimum	4.3175e-008 m	1.6168e-010 m/m	17.481 Pa
Maximum	2.0932e-006 m	2.583e-005 m/m	5.2938e+006 Pa
Minimum Occurs On	Solid		
Maximum Occurs On	Solid		
Minimum Value Over Time			
Minimum	4.3175e-008 m	1.6168e-010 m/m	17.481 Pa
Maximum	4.3175e-008 m	1.6168e-010 m/m	17.481 Pa
Maximum Value Over Time			
Minimum	2.0932e-006 m	2.583e-005 m/m	5.2938e+006 Pa

Maximum	2.0932e-006 m	2.583e-005 m/m	5.2938e+006 Pa
Information			
Time	1. s		
Load Step	1		
Substep	1		
Iteration Number	1		
Integration Point Results			
Display Option		Averaged	
Average Across Bodies		No	

Material Data

EN8

Table 38
EN8 > Constants

Density	7850 kg m^-3

Table 39
EN8 > Tensile Yield Strength

Tensile Yield Strength Pa
2.8269e+008

Table 40
EN8 > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
5.85e+008

Table 41
EN8 > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.04e+011	0.29	1.619e+011	7.907e+010

EN24

Table 42
EN24 > Constants

Density	7850 kg m^-3

Table 43
EN24 > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	2.05e+011	0.285	1.5891e+011	7.9767e+010

Table 44
EN24 > Tensile Yield Strength

Tensile Yield Strength Pa
4.7e+008

Table 45
EN24 > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
7.45e+008

6.4 Comment on ANSYS result

1) Stress and strain distribution in case 1 is less as compared to case 2.
2) Total deformation in case 1 is less as compared to case 2.

6.5 Future scope

In order to reduce maximum total deformation, it requires applying some other optimization technique with material optimization, which is as follows.

1) Fillet radius should be applied on teeth of both gears to reduce the deformation of gear teeth.[8]
2) Increase the face width to reduce the stress at contact of fillet region. (Optimum value of face width=25 mm)
3) Hardening the gear surfaces with heat treatment and carburization will increase the strength of gear.
4) Shot penning can be done to improve surface finish.
5) When the gear is subjected to load then high stress developed at the root of the teeth. Due to this high stress possibility of fatigue failure at this location. Hence it is important to minimize the stress. This stress can be minimized by introducing stress relief feature at stress zone. [9]

Chapter 7

Conclusion

7.1 Conclusion:-

- By comparing results of Weighted Point Method (WPM), TOPSIS Method and COPRAS Method, we suggested that EN30A material is secured with first priority and EN24 material is secured with second priority.
- ANSYS result indicates that, maximum equivalent stress, maximum equivalent strain and total deformation of case1 are less as compared to case2.
- In order to achieve maximum reduction in teeth deformation, it is better to apply other optimization tricks (Specified in future scope) with material optimization.
- Hence by studying selected ranking methods and analysis report, we concluded that for planetary gear box, EN 30A material is suggested for pinion and EN24 for gear.

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