COMPARATIVE ANALYSIS OF METAL MATRIX COMPOSITE AND FIBER REINFORCED POLYMER COMPOSITE FOR A GEAR

THESIS

Submitted in fulfillment of the requirement of degree of

DOCTOR OF PHILOSOPHY

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J.C. BOSE UNIVERSITY OF SCIENCE & TECHNOLOGY, YMCA

by

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CANDIDATE’S DECLARATION

I hereby declare that this thesis entitled **COMPARITIVE ANALYSIS OF METAL MATRIX COMPOSITE AND FIBER REINFORCED POLYMER COMPOSITE FOR A GEAR** by **ATUL SHARMA,** being submitted in fulfillment of the requirement for the Degree of Doctor of Philosophy in MECHANICAL ENGINEERING under Faculty of Engineering & Technology of J.C. Bose University of Science & Technology,YMCA, Faridabad, during the academic year 2020 is a bona fide record of my original work carried out under guidance and supervision of **Dr. M.L. AGGARWAL, PROFESSOR, MECHANICAL ENGINEERING DEPARTMENT, JCBUST,YMCA, FARIDABAD and Dr. LAKHWINDER SINGH, PROFESSOR, MECHANICAL ENGINEERING DEPARTMENT, JCBUST, YMCA, FARIDABAD** and has not been presented elsewhere.

I further declare that the thesis does not contain any part of any work which has been submitted for the award of any degree either in this university or in any other university.

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CERTIFICATE

This is to certify that this Thesis entitled **COMPARATIVE ANALYSIS OF METAL MATRIX COMPOSITE AND FIBER REINFORCED POLYMER COMPOSITE FOR A GEAR** by **ATUL SHARMA,** submitted in fulfillment of the requirement for the Degree of Doctor of Philosophy in **MECHANICAL ENGINEERING** under Faculty of Engineering & Technology of J.C. Bose University of Science & Technology,YMCA, Faridabad, during the academic year 2020 is a bona fide record of work carried out under our guidance and supervision.

We further declare that to the best of our knowledge, the thesis does not contain any part of any work which has been submitted for the award of any degree either in this university or in any other university.

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ABSTRACT

Glass fiber reinforced polymer (GFRP) composite gear is used in a number of applications where fine motion transmission and silent rotation is required. In order to increase its usage there is a need to increase the quality of gear. Shrinkage problem is associated with injection molded gear. In present case blank is prepared by injection molding and teeth are cut on gear shaper by which metrology can be controlled by optimizing the machining parameters. An analysis of variance was applied on 27 experiments to validate the process and found out that rotary feed is at rank 1 which is 0.15 mm/stroke, cutting fluid ratio is at rank 2 which is 12%, cutting speed is at rank 3 which is 240 stroke/min, fluid flow rate is at rank 4 which is 30 ml/min. By using these parameters optimum performance obtained is 0.213 mm root diameter deviation (RD), 0.165 mm tooth thickness variation (TT) and 1 µm roughness average (R_a) with grey relational grade of 0.8318. The optimum response provided the best value of RD, TT and R_a for the range included in experimental results which is 0.138 to 0.416 mm, 0.012 to 0.187 mm and 1.2 to 2.43 µm respectively. Surface roughness improvement in this work is 49.8 % higher as compared to result available in literature.

For the optimization of surface roughness alone which is one of the response affecting noise and gear life, polyamide 66% polymer 33% glass fiber composite spur gear fabricated in three steps: blanks are produced by injection molding process, machined on lathe machine and teeth cut on gear shaper. An attempt has been made to investigate the effect of gear shaping process parameters like rotary feed, cutting speed and cutting fluid ratio on surface roughness during machining. Response surface methodology (RSM) is used to design the experiments and analysis. Optimum values of rotary feed ,cutting speed and cutting fluid ratio during shaping operation of glass fiber reinforced polymer (GFRP) composite gear is used to minimize the surface roughness and results validated experimentally. Analysis of variance (ANOVA) is carried out to analyze the effect of process parameters and their interaction on the surface roughness of the gear teeth. Response surface is generated to find out the minimum surface roughness and the corresponding cutting parameters. Optimization is done after studying effect of various parameters on surface roughness of composite spur gear materia

For slightly more loads, Aluminium silicon carbide metal matrix composite spur gear is the roght choice. It has low density, good strength to weight ratio, excellent castability and corrosion resistance. During working, the root of the spur gear teeth is subjected to stress concentration and crack initiation starts leading to failure of material. Here, the effect of varying fillet radius on stress and strain at the root of spur gear is estimated. FEA analysis is used for building the model for predicting the design parameters at varying fillet radii. The effect of the root fillet radius variation on design parameters of metal matrix composite consisting of Aluminium and Silicon Carbide on its strength is analyzed.

For noise of AISI 4140 steel, particulate composite material of aluminium sicp and glass fiber reinforced polymer spur gear pairs have been selected as three materials for experimental investigation. The noise of all the three material compared through experimental set up. The noise level was measured for the pair of spur gear of these three different materials at various speed of rotation. The results indicates that glass fiber reinforced polymer spur gears are better than metal gears in light load power transmission applications due to their lesser noise.

On a broad spectrum, current study has presented the improved surface roughness, root diameter deviation, tooth thickness variation for glass fiber reinforced polymer among steel and metal matrix composite for light load, low noise applications. This study has also demonstrated the affect of fillet root radius variation on load carrying capacity of gear made up of metal matrix composite. The affect of shot peening and sand blasting has improved the surface properties of metal matrix composite and glass fiber reinforced polymer respectively.

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LIST OF ABBREVATIONS

ANOVA	Analysis of Variance
CAA	Computer aided analysis
CFRP	Carbon fiber reinforced polymer
dBA	decibel on scale A
DF	Degree of freedom
DOE	Design of experiments
EDM	Electric discharge machining
F	Rotary feed
FEA	Finite element analysis
FOS	Factor of safety
FRP	Fiber reinforced polymer
FR	Flow rate
GFRP	Glass reinforced polymer
GRA	Grey relational analysis
MMC	Metal matrix composite
MS	Mean Square
NVH	Noise, vibration, harshness
P	Probability value
PMC	Polymer matrix composite
R	Cutting fluid ratio
R_a	Surface roughness
RD	Root diameter deviation
RPM	Revolution per minute
RSM	Response surface methodology
S	Cutting speed
Sic	Silicon carbide
SS	Sum of squares
TT	Tooth thickness variation
WEDM	Wire electric discharge machining
d	Pitch circle diameter
da	Outside diameter

db	Base circle diameter
df	Root diameter
h	Tooth height
ha	Addendum
hf	Dedendum
Hz	Hertz
m	Module
t	tooth thickness
W	Face width
z	Number of teeth

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

So far the mechanical power transmission is concerned gear is the most important and frequently used machine element. New developments in machines of different fields like medical, automotives, office machines, aviation, cleaning machines demand for refined gearing technology. A simplest machine consists of gear pair, shaft, bearing and sealed lubricated housing in which variable torque and speed is obtained from input to output. Gear always gives the positive transmission.

They are toothed components which transmit power between two shafts by meshing without slip. In gear pair, the smaller element is called pinion and the larger element is called gear which is driving the other is not the criteria. When smaller is the driver gear, it results in step down in driving system in which the output revolution per minute decreases and the transfer load increases. On the other hand, when the larger is the driver gear, it results in step up in driving system in which the output revolution per minute increases and the load transfer decreases.

1.2 TYPES OF GEARS

Different types of gears are:-

(i) Spur gear (tooth parallel to axis)
(ii) Helical gear (tooth inclined to axis)
(iii) Double helical gear or herringbone gear (tooth inclined to axis in opposite direction)
(iv) Internal gear (tooth on inner circle)
(v) Rack and pinion (tooth having Infinite pitch circle diameter)
(vi) Straight bevel gear (tooth at 45 degree to axis)
(vii) Spiral bevel gear (tooth at 45 degree to axis and inclined)
(viii) Hypoid bevel gear (tooth at 45 degree to axis and inclined in opposite direction)
(ix) worm gear (semi circular tooth)
(x) Spiral gear (parallel to axis with spiral shape)

In the gear family, spur gears as shown in Figure 1.1 are frequently used which have their teeth parallel with respect to axis and finds application in transmitting load between two shafts parallel to each other. They are of simple shape, easy to machine and cheaper. They give high efficiency and good rating. They find application in high speed and high torque application in number of gear trains and a number of transmission ratios are possible. Hence, they are used in office machines, household machines, motor bikes, automobile industry, railway industry, aviation etc. When the application is to transmit power at right angle and fatigue is important spiral bevel gears are recommended.

1.3 GEAR MATERIALS

Power transmission takes place when tooth of pinion and gears results in rotation at pitch circle diameter and slipping between addendum / dedendum region in tooth interface. Material of the tooth goes under deflection and sliding of surfaces during torque transmission. The selection of stronger material allows the choice of finer geometrical parameters and vice versa. Very important difference between material and tolerances is that the tolerances are often varied independently. On the other hand, material properties can be inherent and may not be varied independently but in some cases for example steel, core hardness remains the same but surface hardness could be increased by case hardening processes. Following materials may be selected for the gear:-

(i) Cast iron (for low cost, low power, low noise transmission)
(ii) Ductile iron (for low cost and moderate power transmission)
(iii) Grey cast iron (for low cost, lubrication free, low noise and low vibration)
(iv) Cast alloy steel (for big high strength gear)
(v) Through hardened alloy steel (for small high strength gear)
(vi) Surface hardened alloy steel (for small high surface strength gear)
(vii) Carburized steel (for high carbon content at the surface)
(viii) Nitride steel (for hard layer at the surface)
(ix) Through hardened alloy steel (for big high strength gears)
(x) Metal composite (for light weight, low noise and high strength gears)
(xi) Polymer and polymer composite [1]

1.4 ANALYSIS OF GEAR DESIGN

The composite material can be defined as a material made up of base material and reinforcing ceramic material. Their combination results into superior properties in terms of strength, wear, thermal properties then their basic nature.

In a composite material if the matrix is the metal and reinforcement is ceramic. Resulting material is metal matrix composite (MMC). It reflects properties of metal like light in weight, thermal properties, ductile in nature and ceramic properties of reinforcement like high compressive strength, high wear properties, thermally stable. In this way it is possible to obtain a material having properties of both, to challenge the current requirement of gear materials. Composite materials are finding new places in various mechanical applications including gear industries. MMC uses metal as the base and ceramics as the reinforcement. For light weight requirements aluminium is reinforced with silicon carbide to construct the MMC.

Polymers are light in weight and suitable for making gears but its usage could be enhanced if the strength and thermal stability increases. In the polymer composite material (PMC) polymer like polyamides, nylon are used as matrix material and ceramic fiber are used as reinforcement to enhance the properties of polymers known as fiber reinforced polymers (FRP). Glass fibers are frequently used as reinforcement because of its low cost, ease of availability. Resulting materials known as glass fiber reinforced polymer (GFRP).Composite gear materials can be analyzed with finite element modal because of uniform spread of material properties [2,3].

1.5 MANUFACTRUING OF GEARS

Gears manufacturing includes forming, machining and finishing. In the case of forming the whole finished gears produced at once from mold or die cavity. In the case of machining, tooth generation takes place one by one. In the finishing process the gear generated by machining and forming gets their surface finished by application of fine abrasive material.

Various forming methods of gears are listed below:-

(i) Casting (molten metal poured in mould having shape of final gear)

(ii) Powder metallurgy (metal powder compacted in mould with pressure)

(iii) Injection molding (semi solid polymers injected in gear shape mold)

(iv) Extruding (circular long rods of non ferrous material pushed from gear shape dies)

(v) Cold drawing (steel rods pulled from gear shape dies)

(vi) Stamping (sheet metal gears produced by dies and punches)

Various machining processes are listed below:-

(i) Form milling (tooth shape cutter having same module are used in horizontal milling machine)

(ii) Rack generation (rack cutters are used to machine circumference of blank)

(iii) Gear Shaping (gear shape cutter by reciprocating and rotation produce teeth on gear blank on gear shaping machine) as shown in Figure 1.2.

(iv) Hobbing (tooth shape cutter with grooves used to produce teeth on blanks)

Various gear finishing processes are listed below:-

(i) Shaving (similar to gear shaping but accurate cutter is used)

(ii) Grinding (form grinding wheels are used for grinding involute surface of tooth)

(iii) Burnishing (hard and ground gears are run with rough cut gears)

(iv) Lapping and Honning (gears having abrasive coated teeth run against rough cut)

Manufacturing of gear by shaping method is the flexible one as it can accommodate design and volume along with its geometry and cutting forces could also be analyzed [4]. The quality of gears including geometrical and dimensional tolerances can be controlled by use of mathematical models [5]. Ideally the involute profile of tooth is recommended as it transfer load at 20 degree and at constant pressure angle. Gear shaper could be used for making internal gears and splines there by giving flexibility of modification of profile [6]. Helical gears are used where load is higher and silent motion is required. For the particular applications metal powders are compressed in dies and special allowances were given on punches [7].Gear hobbing is recommended for producing the gear in higher volumes so the surface roughness is higher. For increasing the tool life of hob cutter coating is provided. It is possible to design the special tool which can last long [8].The tools by powder metallurgy could be obtained like high speed steel to give higher production volumes [9].

1.6 VIBRATION AND NOISE IN GEARS

When the torque transmission is taking place rotation is there at pitch circle diameter and sliding is there at addendum and dedendum region. Vibrations are caused firstly when tooth of one gear strikes at tooth of another gear due to uncontrolled tolerances during manufacturing secondly due to deflection of material of tooth.

Gear tolerances are provided on tooth including tooth thickness, root diameter, tooth width etc to control vibration and noise. Involute shape of the tooth is responsible for transmission of the power at constant pressure angle of 20^{o}.

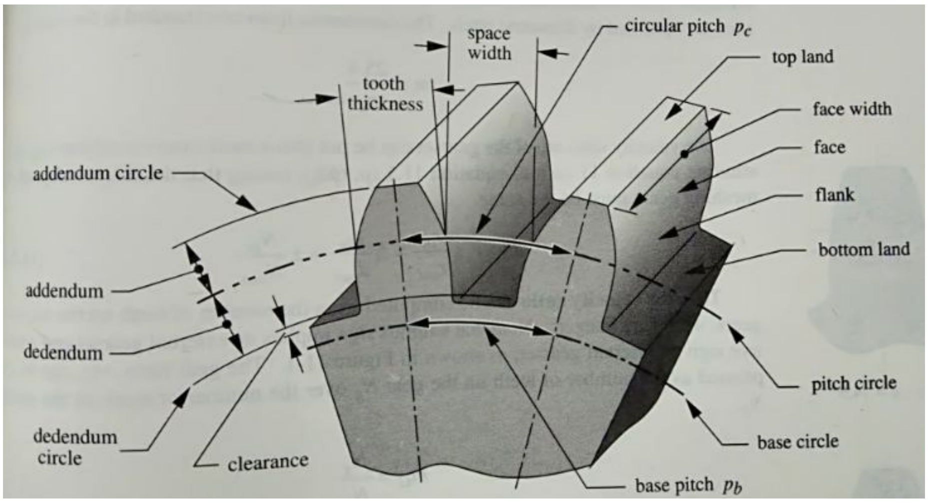

Figure 1.1 Spur gear specifications

Tooth height consists of addendum and dedendum which are situated at above and below the root circle diameter as shown in Figure 1.1.Transmission error could be controlled firstly by selecting proper manufacturing method in which tolerance could be maintained. Secondly error could be controlled by selection of proper material. It has been found that theoretically when involute shape of pinion tooth overlap exactly with involute shape of gear tooth without any load transfer, there would not be any vibration during power transmission. Noise is generated by vibrations in practical situations due to load transfer of gear tooth in gear box but it is important how to minimize it.Demand for silent and light weight moving gears increasing day by day in gear box.

Power transmitting steel gears demands new materials in order to reduce weight, noise, vibration, lubrication, corrosion, dimensional variation and surface roughness. Materials including MMC and GFRP composite show such properties which can maintain the dimensions of gear even in harsh environment. GFRP gear is lighter, generates less noise, less vibration, work without the application of lubrication, when compared with MMC and steel but injection molding of these gears is associated with shrinkage problem which affect the accuracy and life of gears.

Gear forming process affects the performance of gears. Generally polymer gears are manufactured by injection molding machine but due to shrinkage accuracy problem is associated with gears. Injection molded polymer gears are widely used in commercial application due to its Noise, vibration, harshness (NVH) Characteristics but due to shrinkage problem geometry of the gear greatly affected and reduce transmission efficiency with the passage of time [11].

Gear hobbing and shaping are the two economical methods for producing teeth on the circumference but gear shaping process is better if volumes are moderate and gear with collar, internal gear could also be machined. A change in the tooth engagement and disengagement at the pitch circle diameter governs the efficiency of power, uniform torque transmission and silent rotation of the gear. The noise, vibration and life of the gear depend upon the time for which the teeth come to meet at the pitch circle diameter again and again. A slight dimensional variation results in reduction of gear life. The GFRP composite material is light in weight and high strength, which make it suitable to be used in power transmission application. The hard glass fiber in polymer matrix is difficult to cut and shows unpredictable dimensional stability during machining on gear shaper but it could be optimized by selecting the cutting parameters in gear shaper [12]. Such application motivates researchers to optimize the cutting parameter which governs the quality of gears.

1.7 FAILURE OF GEAR

The prime purpose of the gear is to transmit power efficiently and effectively but due to overloading and improper design, failure takes place. There are three types of failure of gears as listed below:-

(i) Failure of tooth: - In this tooth fails at root diameter during power transmission that results in completes stoppage of machine. This is caused when bending stress exceeds the yield strength of the material at fillet root radius of gear. This could be avoided by increasing the module or by increasing the fillet root radius.

(ii) Damage of gear surface: - Due to high contact forces and sliding in the addendum and dedendum region the layer of surface removed from the parent material. This could not result in complete stoppage of machine but noise, vibration, forces on shaft, bearing increases. This could be avoided by changing material or by increasing the hardness of surfaces in contact.

(iii) Scoring:- When sliding speed is very high then metal of the top surface of gear melts and get welded on another place of gear tooth profile, this is similar condition of fatigue but takes place at the initial life of gear.

For efficient and effective usage of material all the three types of gear failure modes should be taken into consideration. However if speed is low then scoring could be overlooked but it would create a serious problem for high speed gearing. Bending strength could be increased by using coarse pitch gears but it results in high sliding speed due to large addendum and dedendum. It means by increasing surface strength fine pitch gears could be used for transmission. Surface strength could be increased by changing material, increasing hardness at surface by heat treatment and shot peening methods.

1.8 WORKING OF GEAR SHAPER

In the gear shaper rotary feed controls the rotation of gear blank in front of the cutter as the rotary feed decrease the number of cutter strokes per teeth increases. It means cutter passes through the unmachined surface repeatedly and the surface which remains uncut get cut due to the overlapping of the cutter stroke. The rotary feed (F) is controlled with the help of change gears in the gearbox.

One gear is attached with cutter spindle which controls the rotation of cutter while another is attached with the table to control the blank rotation. The cutting speed (S) i.e. strokes per minute is controlled by changing the V- belts on pulleys mounted on motor shaft and drive shaft, it indicates the rate at which material is removed from the blank.

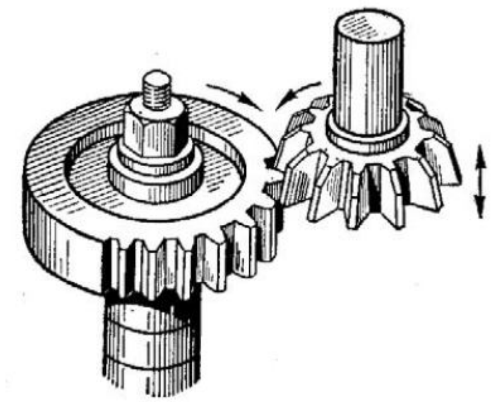

Figure 1.2 Working of gear shaper machine

The cutting fluid chosen is Servo cut S of Indian oil make higher ratio (R) is used for good surface finish and lower ratio is recommended for quick heat removal. Flow rate (FR) is controlled by lever mounted on the outlet of pump. The requirement is chips get quickly wiped out from cutter- work piece interface.

1.9 CAD MODEL OF GEAR

Computer Aided Engineering is used to help engineers in works like analysis, simulation, design, manufacture, planning, diagnosis and repair of gears. Software aids that have been innovated for giving support to these designing of gears are considered CAE tools. It is being used, for example, to judge the robustness and effectiveness of gears and gear boxes. It focuses on analysis, verification and economy of gears and gear machines.CAE tools will be major help of information to support gear designers in decision making. Literature reveal that any gear design engineer can save approx. 30% of cost and time with help of CAE systemsComputer Aided Analysis (CAA) is a technique by which near to approximate solution of a critical gear can carry out. Computer Aided Analysis consists of finite element analysis for working the partial differential equations related to solid mechanics of gears. The two frequently used methods in computer aided analysis are Finite Element methods and Finite Difference method. The second one is used mainly for problems in Fluid Dynamics, while the first one is used in a wide range of practical problems of gears.A CAD model of the gear can be prepared on CREO, CATIA and imported to ANSYS software in which it is divided into finite element number. Spur gears normally failed in beam strength and wear of tooth surface. With the help of FEA (Finite element analysis) it is possible to calculate Von-Mises stress, deflection, deformation and strain on tooth region. Additionally Fillet radius of the spur gear is the point which can be optimized if number of teeth are less than 17 in the case of involute profile for 20^o pressure angel to avoid undercutting and for fine pitch gear root fillet radius is not defined which could be optimized by FEA. By varying the fillet root radius it is possible to obtain different values of stresses, strain, deformation on the model instead of doing the practical analysis saving time and money.

1.9.1 Finite element analysis

The finite element analysis (FEA) is a numerical method for solving engineering and mathematical physics gear problems. The typical use of this method is to solve the gear problems in the field of stress analysis. This method can be able to solve gear problems involving complicated geometrics, loadings and material properties which cannot be solved by analytical method. In this method, the domain in which the analysis to be carried out is divided into smaller bodies or unit called as finite elements.The gear properties of each type of finite element is obtained and assembled together and solved as whole to get gear solution. Based on gear application, the problems are classified into structural and nonstructural problems. Finite Element Analysis (or other numerical analysis), development of structures must be based on hand calculations only. For complex gears, the simplifying assumptions required to make any calculations possible can lead to a conservative and heavy gear design. A considerable factor of ignorance can remain as to whether the gear will be adequate for all design loads. In gear problems, displacement at each nodal point is obtained. Using these displacement solutions, stress and strain in each gear element are determined.

1.9.1.1 Advantages of finite element analysis

(i) Irregular gear geometries can be modeled more accurately and easily.
(ii) Implementation of any type of gear boundary conditions is very easy.
(iii) With very little effort, heterogeneous and anisotropic gear materials can be modeled.
(iv) Any type of gear loading can be handled.
(v) The element sizes can be varied throughout the gear model. Wherever it is necessary. We can use fine meshes.

(vi) Whether the gear problem is linear or non linear, the basics (i.e. steps followed/implemented) of FEA remain same.Altering the element model with different loads, gear boundary conditions and other changes on the model can be done easily.

1.9.1.2 Disadvantages of finite element analysis

(i) FEA software is costlier.

(ii) Output result will vary considerably, when the gear is modeled with fine mesh, when compared to body modeled with course mesh.

(iii) Before using a element for a gear problem, we should know about its capabilities and nature, because no single element is available for all applications.

1.10 SHOT PEENING AND SAND BLASTING OF GEARS

Shot peening is the process of creating residual compressive forces on the surface of gears. It is a cold working process to modify mechanical properties of metal gears and MMC gears. In this process steel shots of different shapes depending upon the characteristics requirement bombarded on the surface of metal gears to create plastic deformation.

Power transmission components characterized by tensile stress after machining which accelerates the fatigue failure often associated with gears, after shot peening this tensile layer replaced by the compressive layer and increases its life. These shots create dimples on the surface and retract back.

The top layer of gear gets compressed and due to this a residual stress develops on the surface. Shot peening has additional advantage of increasing component hardness, removing micro cracks, cleaning surface etc.

1.10.1 Process of Shot peening

The gear is to be shot peened loaded on the table and table moves in the chamber where there is nozzle for bombarding steel shots in tunnel. Velocity of steel shots could be varied in the tunnel it works on the compressive layer of gears. Shapes of shots like spherical, triangular, square, cylindrical gives different effects on the surface of gears, direction of flow of shots incident on the gear could be varied to change surface properties, time of exposure could be varied for obtaining different surface properties of gears.

Inputs of shot peening are:-

(i) Size, shape and hardness of shots
(ii) Intensity of shot
(iii) Coverage of shots
(iv) Type of shot peening machine
(v) Shot velocity

Shot material could be steel, ceramic, glass etc. Type of shot material to be used depends upon the component to be peened. For components like gears, steel shots are used for high intensity peening i.e. impact of peening is at more depth of surface. For low and medium intensity peening glass and ceramic shots are used.

Intensity is related to the force with which the shot strikes the surface of the gear. Almen strip is used to measure the intensity of the shot, in this method a strip is bombarded with shots and the curvature obtained is measured on the almen gauge. Intensity on the gear surface depends upon distance from the shot nozzle, angle of nozzle, velocity of the shot.

Coverage is the surface area of the gear to be covered during the shot peening, root fillet radius of the gear is the area to be strong enough as it affects the bending strength of the tooth, involute surface after shot peening results in pitting resistance and scoring, dimples which is generated after shot peening works like oil pocket for gear teeth during lubrication between sliding surfaces.

Shot peening machines includes centrifugal machines, direct pressure machines and air jet machines. In the centrifugal machine the shots are rotated in the rotor due to centrifugal force get bombarded on gears. In direct pressure by mechanical throwing of shots through nozzle is done. In air jet machine the shots are bombarded through nozzles with the help of air pressure.For measurement of the shot peening specifications AMS2430 standards are used.

1.11 ADVANTAGES OF GLASS FIBER REINFORCED POLYMER AS GEAR

Among the materials available for gear manufacturing if the search is for light weight, high strength, noise less operation, then the polymer gears are having upper edge. The reinforcement of glass fibers, strength is further improved because of presence of hard ceramic reinforcement [15]. Following are the advantages of GFRP:-

(i) It is most suitable for the gear application if the running temperature is below 150^0 C like in office machine, medical machines, hair and paper cutting machines.
(ii) GFRP gears can act as load sharing on entire tooth surface in comparison to metal gears where only line contact is there on pitch circle diameter.
(iii) GFRP gears outperform metal gears in corrosive and chemical atmosphere due to non reactive nature of polymer and glass.
(iv) Due to lower polymer modulus and damping properties GFRP gears are noiseless during operation and suitable to be used at hospital and office machines.
(v) Low material weight increases transmission efficiency due to inertia effect and suitable to be used in aerospace, ships and light automobiles, which further increases fuel efficiency.

1.12 DISADVANTAGES OF GLASS FIBER REINFORCED POLYMER AS GEAR

GFRP gear has some disadvantages as given below:-

(i) These gears are formed by injection molding process which has shrinkage problem.
(ii) Surface finish of tooth surface is low because of glass fiber that comes on surface during solidification
(iii) Because of un even surface on the involute profile transmission error increases
(iv) Machining of GFRP is difficult because of presence of hard glass fiber.
(v) Due to uneven distribution of glass fibers in the polymer matrix machining of gears quality is unpredictable.

1.13 MOTIVATION

The Present work "Comparative Analysis of MMC and Fiber Reinforced Polymer Composite for a Gear" is undertaken due to following reasons:-

(i) Composite materials are now days have been using in number of applications due to light weight, low noise, low vibration and damping in dynamic use. Due to presence of ceramic reinforcement, resistance to wear, good tensile and impact strength is there. It is difficult to machine because of presence of hard ceramic reinforcement those results in high tool wear rate, poor surface finish and high tolerance variation.

(ii) GFRP is a most suitable polymer composite material for gears where running temperature is below 150^0C along with requirement of low noise, low vibration and light weight. As per literature these gears are formed by injection molding, no work is available on machining of it.

(iii) The majority of the research work conducted on improving the life by changing fiber volume, fiber orientation, matrix etc.

(iv) Also earlier no research work found on generation of teeth on gear shaper machine for GFRP. Scheme of research work is shown in Figure 1.3.

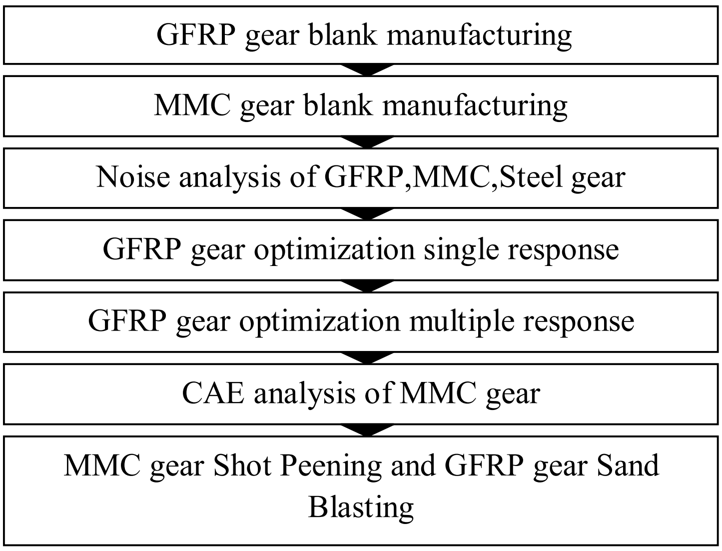

Figure 1.3 Scheme of research work

1.14 ORGANIZATION OF THE THESIS

The thesis work is divided into eight chapters. Each chapter offers a platform for achieving the presented objectives as well as a proper direction for completion of research work. The organization of present Ph.D. thesis work in various chapters is as following:-

CHAPTER 1: INTRODUCTION

This chapter will comprise of introduction to gear shaping process and gear materials – GFRP, MMC, steels. It provides overview of different theories of material removal, comparisons of gear manufacturing methods, advantages and limitations of gear shaping process. This chapter also gives an overview of the research problem, objectives, methodology and thesis organization

CHAPTER 2: LITERATURE REVIEW

This chapter describes the current state of art and literature available in the area of gear manufacturing and gear materials. Major contributions of the past research in prediction of gear metrology and surface roughness improvement and also some theoretical explanation of process mechanism have been discussed. The significant experimental finding related process mechanism of teeth cutting and gear materials were also presented. Based on the literature survey, the identified research gaps have been presented.

CHAPTER 3: EXPERIMENTAL SETUP AND PROCESSES

This chapter will discuss the details of the experimental set-up used and preparation of composite materials. The details of the methodology used in the experimentations were also presented. A detailed description of the methods used in the analysis and optimization were also given in the chapter.

CHAPTER 4: MODELING OF GFRP USING TAGUCHI AND GREY RELATIONAL ANALYSIS

In this chapter, gear shaper machine that uses GFRP material instead of conventional steel has been experimentally analyzed. The chapter presents the effect of process parameters on root diameter deviation (RD), tooth thickness variation (TT) and surface roughness (R_a) during shaping. The experimentation has been performed to determine effect of rotary feed, cutting speed, cutting fluid ratio and cutting fluid flow rate on RD, TT and R_a. It has been found that RD, TT and R_a improved significantly by optimizing the process parameters of gear shaper through Taguchi and grey relational analysis.

CHAPTER 5: PERFORMANCE ANALYSIS AND MODELING OF GLASS FIBER REINFORCED POLYMER GEAR USING RESPONSE SURFACE METHODOLGY

This chapter presents effect of process parameters of gear shaping on machining performance. The machining through Response surface methodology is designed to attain minimum surface roughness by selecting the optimum machining parameters. GFRP composite was used for parametric study. The experimentation was performed to evaluate the effect of rotary feed, cutting speed and cutting fluid ratio on surface roughness. The experimental findings demonstrated that gear shaping process parameters have significant effect on surface roughness.

CHAPTER 6: COMPUTER AIDED ENGINEERING ANALYSIS OF SPUR GEAR

In this chapter model of spur gear of MMC material is prepared and finite element analysis of it was done on ANSYS workbench. Von-Mises stress, strain and deformation were generated by varying tooth fillet radius. For coarse pitch gear, value of root fillet radius is defined as 0.3 times module but for fine pitch gear where module is less than 1.27 is not defined. It has been shown that factor of safety could be increased by increasing tooth root fillet radius.

CHAPTER 7: NOISE ANALYSIS AND SHOT PEENING OF SPUR GEAR

This chapter presents comparison of noise of gear pairs made up of GFRP, MMC, steel. Noise level was measured for various speed of rotation. The results indicate that GFRP gears are better than MMC, steel gears in light load power transmission application due to lesser noise. Shot peening / sand blasting was done on GFRP, MMC gear which results in hardness improvement and generating dimples for storing lubricating oil.

CHAPTER 8: CONCLUSIONS AND SCOPE FOR FUTURE WORK

This chapter summarizes the major findings of the research work. On the basis of current research work, conclusions, limitations, recommendations, scope for future work has been presented.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

As discussed in the previous chapter, the gear formation methods for GFRP, MMC and steel associated with problems related to dimensions. It includes surface roughness and molding. In order to control the output response of gears like noise, vibration, weight, requirement of lubrication, various methods have been adopted by researchers including material selection, machining, different manufacturing process, for gears. Out of the three materials from GFRP, MMC and steel – GFRP is the material having low noise, light weight, good strength, no need of lubrication, corrosion resistance, less vibration and good finish.

Injection molding technique is widely used for gear forming processes for GFRPs but it is having shrinkage problem which affects the dimensional, geometrical and surface finish problems due to the presence of hard glass fibers in polymer matrix. In the applications of automotives, medical machines, office machines, aviation demand is, gears should have low noise in addition to dimensional and geometrical stability. This chapter shows the interest of various researchers in the area of GFRP, MMC, steel, optimization, injection molding, production, machining, manufacturing processes, testing for increasing life of gears, improving surface finish.

Literature survey has been divided into four subsections as listed below:-

a. Gear load testing
b. Machining of fiber reinforced polymer
c. Optimization
d. Tolerances and noise testing

2.2 GEAR LOAD TESTING

Different techniques have been utilized to check the life of gears. Based on test rigs by measuring the tooth root stress, analyzing tooth surface wear, failure patterns. For predicting life of gears in practical applications load, time of action, lubrication, fiber orientation can be studied. Current section is based on the literature review in the area of testing.

Senthilvelon et al. (2004) [16] investigated the damage mechanism in injection molded gears made up of unreinforced, glass and carbon reinforced Nylon66 spur gears on power absorption type test rig and observed that material composition and applied torque decides the type of failure mechanism. Investigations depicted that low interfacial strength between fiber and matrix causes fiber pullout. Due to superior mechanical strength and thermal resistance reinforced gears exhibited longer life in comparison to unreinforced gears. It was observed that at tooth bending stress of 25 MPa surface temperature of carbon reinforced gear is less in comparison to glass reinforced gear due to tooth stiffness, heat generation, and dimensional stability.

Singh et al. (2018) [17] tested the three polymer gears made of acrylonitrile butadiene styrene (ABS), highdensitypolyethylene (HDPE), polyoxymethylene (POM) by varying the torque and speed of gears in test rig and found that by changing the torque at fixed range, speed at fixed range, torque is the more contributing factor for temperature rise than speed. POM gears have dimensional stability at more fatigue cycles. ABS gear fails in wear of tooth surface whereas HDPE gears fails at root of tooth.

Mao et al. (2015) [18] worked on the wear behaviour of machine cut acetal gears and gears manufactured by injection molding processes. Gears were tested in the range of torque at fixed speed. Number of cycles varies within the fixed cycles. It is found that as the load reaches the critical value for this particular temperature wear increase due to softening of teeth for both gears manufactured from different processing roots It is also found that at 1000 rpm and torque of 8.2 Nm the gear materials reaches at 165^0C which is melting point of acetal.

Mertens et al. (2016) [19] investigated the performance of polymer gear when assembled with steel gear manufactured from hobbing and steel gear manufactured with wire electric discharge machining (WEDM). Results shows that the hard surface of gear manufactured on wire cut electric discharge machining remove the material from the surface of polymer gear during running having hardness of 72 Shore D which results in more friction with increase in surface temperature. Hobbed gear is having surface roughness of lower range and WEDM gear is having surface roughness of higher range. Test load used for this process is fixed. It has been found that combination of steel gear with hobbed gear shows lesser life in comparison to combination of WEDM gear with polymer gear due higher surface roughness.

Kim (2006) [20] investigated methods to decrease the surface temperature of mating gears during running in order to increase the life of gears which is the primary reason of premature failures of gears. The study revealed that by inserting a drilled hole near the tooth region due to air ventilation surface temperature of tooth decreased up to 10^0C. Acetal gears were tested at fixed load within the defined speed. Holed acetal gear has longer life in comparison to the solid gear and life of the gears is having 190 % improvement in number of cycles of revolution.

Karthik et al. (2015) [21] presented the study on wear behaviour of gears made up of nylon + silicon carbide (sic), nylon 6 + sic, nylon 30 % glass filled with sic. The wear loss of these gears for 2 million cycles run for 5 hours shows upper life for glass filled nylon with sic powder during running .

Belmonte et al. (2017) [22] presented a study on crack path propagation in short GFRP polyamide (PA) 66 with glass fiber percentage of 0,15,25,35,50 respectively. It has been found that crack length for these order rises from minimum to maximum. The increase of fiber content increases the fatigue strength and higher life of material in service. These results are obtained by using the variable stress. Cycles of load varied with the help of data control mechanism.

Rudresh and Kumar (2017) [23] experimentally investigated wear and friction of PA 66 mixed with polytetrafluroethylene (PTFE) and glass fibres. Matrix material PA66 taken as 80%, Teflon powder and glass fibers varied in the ratio of ; 0%, 5%, 10%, 20%,30%.It has been found that with the increase of fiber content the wear resistance of the composite material increases and coefficient of friction is minimum at 20% of teflon powder.The brittle behaviour of glass fiber has bad effect on wear resistance of material.

Dighe et al. (2014) [24] worked on PA and Poly ether ether ketone (PEEK) with 30% glass fibers. Test rig was set at torque which is variable with respect to time; speed set and for fixed cycles at temperature of 25^0C. Temperature of gear tooth of PA66 with glass fibers varies in higher limits and for PEEK with 30% glass fibers varies in lower limits. Hence it is found that gear made up of PEEK with 30% glass fibers have more stability with respect to temperature which results in more service life.

Pawar and Utpat (2015) [25] compared the test results of MMC gear of aluminium silicon carbide with ansys result by doing the finite element analysis. Bending fatigue test were performed as per SAE J1619 standards for calculating the power of gears. Bending strength was higher in steel followed by MMC and Nylon gears. Through Ansys displacement of Aluminium silicon carbide metal matrix is near to steel at given Von-Mises bending stress for set load at pitch circle diameter. Is has been found that gears made up of composite is having reduction in weights compared to steels for same load carrying capacity.

Williams et al. (1999) [26] explained the effect on shrinkage when powder of silicon and Teflon added during moulding of polymer gears. Different parts of gears like addendum, dedendum, root, centre etc shrink at different rates .a data base related to it has been generated and complied for increasing the precision of the gears. Various methods are complied to measure the dimensions.

Luscher et al. (2000) [27] compared experimental results obtained from injection molding of polyketone gears with model simulation and found out that the injection molding points have direct influence on run out of tooth of polymer gears whereas pressure decreases all form of errors. More the pressure less will be the lead and form deviations on the gear surface. This method is adopted keeping in mind about the high production rates of polymer gears with low cost.

Lin and Kuang (2008) [28] investigated the relationship between applied load and tooth wear in polymer gears. A model has been developed by taking the tooth strength, noise, vibration, temperature rise at the contact points for pitch circle diameter into consideration. It has been found that with the tooth wear load carrying capacity of the gear changes very fast and cumulative effect is that noise, vibration changes accordingly.

Kurokawa et al. (2003) [29] investigated wear rate of carbon fiber reinforced polyamide 12 (CFRP) in comparison to CFRP 6,66 and 46 respectively. It has been observed that when grease is used at pitch circle diameter between mating gear of polyamide 12 having higher life than other variant and due to this property load carrying capacity, noise, vibration reduction also associated with it and water absorbed by this material is also low which is responsible for low fiber pullout from the matrix.

Kim et al. (2013) [30] investigated the life of PA worm gear when reinforced with glass fiber having ratio of 25% and 50%. It has been found that helical gear made up 50% glass fiber reinforcement associated with low tooth wear, noise and vibration. It is also depicted that with the increase of glass fiber content strength and hardness improves but tooth becomes brittle which is not suitable for shock loads. Unequal distribution of the glass fiber in the matrix also affects the strength of gear tooth.

Hirani (2012) [31] investigated the wear rates of gears by measuring the data related to noise, vibration and oil cleanliness. Three test rigs have been developed to gather the data from theses resources and meaning full conclusions have been drawn based on fuzzy system. The use of sensors along with detectors enhanced the process of checking of gear transmission errors. It has been found that surface pitting of the gear surface which increase the noise and vibration levels after cleaning the oil the fine powder of metals is found which validate the surface damage of the gear teeth in the gear.

Shaw et al. (2003) [32] discussed the influence of residual stresses on the durability of gear tooth surface and bending root strength. It has been found that failure of the tooth occurs because of fatigue and material discontinuities and hardness of the surface. Shot peening of the gear produce the residual stresses on the surface of the gear tooth which is responsible for the increase of the life of the gears. From the studies of the alloy steel gear on the resonance fatigue testing machines it is calculated that by developing residual stresses by shot peening the life of the gears can be increased by 75%.

Joardar et al. (2012) [33] worked on the aluminium silicon carbide MMC and found that with the increase of reinforcement the strength and hardness of the MMC increases. Compression of the MMC cylinders can be executed up to 32% and cylinder rupture after the compression of 38%. By this upsetting load is calculated and compared with finite element simulation and results found close to the experimental results. Aluminium alloy LM6 with silicon carbide particles is placed within their limits for the application in machines.

Kumar et al. (2014) [34] examined the wear of spur gear pairs by obtaining the scanned information and this information further studied to obtain the remaining life of gear by adjusting the backlash of the gears. Based on this studies it is possible to predict the failure of the tooth surface and to further utilized the gears without any premature failures. It is tested that if there is data available about the health of the gears which includes contact length, backlash, center distance, tooth wear out portion, involute profile then by changing the working conditions the gears could be further used.

Jebur et al. (2011) [35] compared the results of PA spur gears obtained by inserting sensor in between the tooth surface and results obtained from the finite element analysis and this was within the range of 12.86 % and hence this model could be used for prediction of stress levels without any use of costly test rigs. It has been found that module of the gear effects the contact stresses reduction in module corresponds to low tooth strength. The critical section of the gear could be modified to increase the load carrying capacity.

Stringer et al. (2011) [36] evaluated tooth bending strength of spur gear on newly developed test rig in which it is possible to conduct the fatigue test up to 1000 million cycles in short time. The experiments performed shows different results as calculated from data acquisition and sensor measurement so this approach is more practical. The study revealed that correction of the factors is required in sensor based bending strength calculations.

2.3 MACHINING OF FIBER REINFORCED POLYMER

Machining of fiber reinforced polymer (FRP) is associated with problems like surface roughness, surface cracks, small tool life and temperature gradients. Orientation of the glass fibers in matrix affects life of gear and surface finish. Ratio of the fibers, their strength with matrix is responsible for delamination of layers. These problems affect gear properties.

Habib and Okada (2016) [37] explained the possibility of machining of CFRP on electric discharge machining. Based on the experiments it is found that material removal rate is directly proportional to pulse on and off time, peak current, electrode speed, voltage etc. Graphite electrode had higher material removal rate than copper. Surface roughness was low in copper electrode than graphite. Wear of the electrodes decreased with the decrease of machining parameters.

Madhukrishnan et al. (2016) [38] analyzed the influence on surface finish of the machines surface of GFRP. Surface finish decreased with the increase of feed rate and increased with the cutting speed of spindle. High speed steel drill generated low surface finish while tungsten carbide drill generated high surface finish. At higher feed rate fracture was high and uncontrolled. Solid carbide drill showed high twist strength. The performance of solid carbide drill was at number one, tipped carbide was at number two and high speed steel was at number three.

Gao et al. (2015) [39] studied the effect of more than one machining parameters on the quality parameters. Fiber orientation showed different surface finish for 45^0 and 135^0. It was good at 45^0 and low at 135^0. The important factor for surface finish was depth of cut, cutting speed and cutting force. It was found that fiber orientation is the more influencing factor for surface roughness.

Niu et al. (2015) [40] investigated the machining of carbon reinforced polymer and proposed model for predicting the cutting forces. Surface roughness is associated with the fiber pullout during the different cutting angles and fiber orientations. The results obtained for cutting forces and chip length and get compared with experimental values and it was found that both were within the allowable limits. Chip length was associated with cutting forces.

Wang et al. (2017) [41] carried out milling of CFRP and found four fracture criteria of carbon fibers first was due to bending of fibers, second was due to shearing of carbon fibers, third was compression of carbon fibers and fourth was pull out of the carbon fibers due to detachment of fibers from the matrix. It was found that pull out of the fibers was the primary reason for formation of the surface roughness followed by bending and shear. It was proposed that by inclining the milling cutters surface roughness could be improved.

Ha et al. (2016) [42] studied cutting temperature and cutter dimensions on surface roughness while machining CFRP drilling at high cutting speed. It was found that combination cutter is having high surface finish in comparison to the four flute cutter.

The blackening of the top surface took place when cutting temperature exceeds the bonding temperature of the epoxy. In the star cutting temperature was high due to lower temperature at the top but as the temperature was increased due to melting of the polymer cutting force was reduced. The use of cutting fluid at high speed reduced the surface roughness at top and bottom surface of the flats.

Voss et al. (2017) [43] investigated the effect of orientation of fibers, geometry of the cutting tool and parameters of the machining on the surface roughness of the CFRP. Tool consumption was dependent on the material which remains in contact with the tool during machining. Rake angle was the contributing factor for the chip flow and chip getting jammed with in the chip tool interface. By increasing the clearance angle between tool and material, surface roughness reduction takes place. An equation was developed and validated with experimental results.

Fieiei (2017) [44] noted the drilling parameters on delamination of top and bottom layer. It was found that feed rate was directly proportional to the wear out of top and bottom layers. Cutting speed was inversely proportional to the wear of top and bottom layers. Surface roughness was directly proportional to the feed rate and inversely proportional to the cutting speed. Carbide tools were responsible for the good surface finish. Fiber pullout took place at low feeds and could be controlled by increasing the feed rates. Drilled surface demonstrated the presence of distortion of the surface.

Helfrich et al. (2017) [45] studied that additional cutting forces attributed to more number of layers of carbon fibers. It was found that layers of the carbon fiber followed by glass fiber layers reduce the machining force. The tool angles greatly influenced damage of the fibers and division of forces within the matrix. The relation between the cutting speed and feed rate was not fully confirmed. Experiments were performed on continuous and discontinuous long fibers. Six different material combinations were used for different layers of carbon and glass fiber layers.

Rentsch et al. (2011) [46] reported about the experimental machining and simulation of it on the model. It has been found that the results are near to the experimental values for material removal rate but for cutting force and thrust force were slightly at lower level. The load component of the tool while machining was present in the actual experimentation but in the simulation it completely vanishes.

Ismail et al. (2016) [47] did the study on machining of new and ordinary FRP. It has been found that surface roughness and fiber delaminating effect is optimum for 0.1 mm/rev of feed and 30 m/min of cutting speed. The hemp fiber reinforced polymer (HFRP) material had minimal delaminating effect while CFRP had minimal surface roughness. The wear rate of the high speed steel drill was predominant for 64 holes however there was no effect on the HFRP. When drill diameter was increase it was found that the surface roughness was more than the delaminating effect.

Sorrentino et al. (2017) [48] investigated the machining of CFRP with help of diamond tool with electroplated surface through milling process. The cost and quality of machining of the diamond polished tool was compared with tool having inserts on the upper face. The cutting force generated in the case of diamond polished tool was lower at about 25% than tipped tool because of the surface contact of the cutting surface is more. The surface finish obtained with diamond polished tool was high in comparison to tipped tool but the cost was higher than the tipped tool.

Azmi el al. (2012) [49] investigated the end milling process on the GFRP materials. It was found that the abrasive nature of the glass fiber was responsible for tool wear in the interface. Despite of the use of strong tool the uncut fibers and fiber came because of the delaminating factor in between the uncut material and tool increased the surface roughness. Theoretically Taylors equation was used to calculate the tool life in cutting which showed good accuracy. It was found that cutting forces increases due to wear of the cutter.

Spitas et al. (2006) [50] investigated the machining of circular fillet in gear tooth of polycarbonate material and worked on the load carrying capacity of these gears. A new hob cutter for generating circular fillets had been designed and gears produced. The load carrying capacity of these gears checked with standard trochoidal fillet.It was found that bending stress, deflection, deformation, factor of safety, elastic strain were optimum for circular fillet. This manufacturing overcomes the problem of undercutting of lesser number of teeth in hobbing process.

Kenda et al. (2014) [51] studied the machining of the gear mould with the abrasive flow for the plastic gears. For his WEDM was studied and it have been found that rough layer, cracks, scratches influence the final finishing of the polymer gears. With the application of abrasive flow machining the pre machining impressions of the material could be completely removed. A model for the prediction of the surface finish and layer of the material removed from the WEDM machined surface accurately developed. It has been found that gear surface finish obtained from the polished surface than the rough surface mould was almost more than twice.

Smith et al. (2015) [52] revealed that machining of the composite materials with help of diamond drills in the core improved the surface finish. The core drills machined the surface on the internal and outer area from the two edges on the circumference. Cutting forced produced by the electroplated drill are more in comparison the poly crystalline drills (PCD) drills. Temperature rise on the surface was more during the machining by PCD drill in comparison to the electroplated drills.

Planikumar et al. (2011) [53] analyzed drilling of the GFRP composite materials and found that feed rate had great impact on machining force and surface finish during the machining. Spindle rpm has least effect on the cutting of the holes. Grey relational analysis was done for the multiple responses. It has been found that drilling at low feed, high cutting speed, small drill diameter attributed to the high surface finish.

Behara et al. (2011) [54] analyzed the cutting and upsetting of the aluminium silicon carbide MMC at higher temperature. It has been found that with the increase of sic hardness increases and the cutting force also increases. At constant feed rate in machining process power requirement increases by increasing cutting speed and depth of cut. The peak current and pulse duration were selected as the process parameters to evaluate the MRR, EWR and R_a as the output responses.

2.4 OPTIMIZATION

During machining of composite materials there is need of optimization of machining parameters to control the best combination of response which could be single or multiple. Many techniques like response surface methodology, grey relational analysis, Taguchi techniques, principal component analysis etc are available for getting the quality responses by selecting optimum parameters.

Singh et al. (2012) [55] dealt with the optimization of shot peening parameters for stainless steel plates. In this hardness, tensile strength and surface roughness was optimized by using grey relational analysis and Taguchi methods. It was found that significant parameters influence the output characteristics by 95% confidence level.

Regression model had been developed for surface roughness, hardness and tensile strength with the shot peening process parameters. It was found that grey relational grade is nearby for predicted values and experimental values.

Yang et al. (1998) [56] did the optimization of turning parameters for steel bars using Taguchi method. The study revealed that there is interdependence of tool life with cutting parameters of lathe machine like cutting speed, feed rate, depth of cut. It was found that for higher signal to noise ratio the tool life is more and as the Signal to noise ratio decreased the tool life reduces.

Wang et al. (2016) [57] related machining force and temperature of the tool during machining of CFRP composites by using surface response methodology. It was found that cutting speed is having more influence on temperature in comparison to speed of cutting and depth of cut along the radius. Feed rate affected the machining force at tool chip inter face. Cutting sped at low values, feed rate at low values and depth of cut at higher level responsible for better surface integrity and more material removal rate. It was depicted that when cutting temperature go beyond the melting point of matrix it was not able to hold the carbon fiber so surface distortion started.

Gupta and Kumar (2015) [58] presented the optimization of removal rate of material and surface properties of unidirectional GFRP by using principal component analysis and Taguchi method. In the turning process the surface roughness was influenced by feed rate with the increase in feed rate the surface integrity reduces. A model had been developed for the determination of surface roughness using principal component analysis. Five machining parameters were optimized for surface roughness and material removal rate.

Chabbi et al. (2017) [59] analyzed turning operation on lathe machine for the polyoxymethylene polymer for surface integrity, machining force, power to cut. The optimization includes the balance between quality in dimensions, surface finish and production rates. It was found that surface integrity depend upon feed rate, depth of cut, cutting speed in descending order. Machining force was greatly influenced by depth of cut and after that feed rate and machining speed. Removal of the material related with depth of cut, feed rate and speed of cutting in descending order. The correlated coefficient models were at 98% confidence level.

Bardhan et al. (2010) [60] related the density of iron powder parts and process parameters of powder metallurgy using response surface methodology (RSM). It had been found that load of compaction, temperature and time increases the density of sintered parts. A second order model had been developed by RSM and validated with ANOVA. It was found that experimental values were matching with predicted model within 15% error. In the case of powder metallurgy technology there was requirement of high density parts in automobile technology, aviation, navigation for enhanced life at sever load application which was possible by modeling of the process parameters.

Karatas and Gokkaya (2018) [61] presented the study on cutting nature of CFRP and GFRP composite materials. Studies showed that feed rate increment reduces the surface integrity so lower feed rates were recommended for low surface roughness. In both the cases surface finish increases with the decrease of feed rate. Non conventional methods were adopted by researcher for machining of CFRP and GFRP and found that increment in feed rate increases cutting forces and length of cracks.

Saravanan et al. (2016) [62] analyzed material for brake disc to reduce the cost of it. From the study it was finalized that brake disc with 10% cenosphere is good for machining of material. The stability of material at higher temperature was tested at practical experimentation. Costing of the material was compared with AA 6063. It was reported that there was cost reduction of about 2.5%. The weight reduction was optimized to about 20% lesser. There was improvement in life cycle of the brake disc.

Kapelevich and Shekhtman (2009) [63] carried out the experimental study on tooth fillet profile optimization for gears with symmetric and asymmetric teeth. Results revealed tooth root fillet optimization results in 10-20 % reduction in bending stress in comparison to ordinary tooth fillet involute profile. This further improved the deflection, deformation, elastic strain and factor of safety. It was revealed that tooth root is the portion of gear which leads to increment in life, efficiency and effectiveness.

Ghosh et al. (2014) [64] developed model for wear response of MMC having base metal as aluminum and reinforcement as silicon carbide particles. Taguchi analysis and grey relation analysis was performed for optimization of the test process. Single output response was taken as wear and test parameters were taken as load, sic percentage, speed and time. It was found that reinforcement percentage had the great influence on wear of composite. Load and speed are the important factors and within the range, time had very less impact on the wear. It was found that if process parameters could be optimized life of the component could be enhance by 17%.The wear was observed as abrasive in nature.

Sait el al. (2009) [65] carried out the study of pipes machining made up of GFRP and optimized machining parameters were obtained by the application of Taguchi and desirability function analysis. Turning operation was performed on filament wounded and hand woven GFRP pipes with help of carbide tools. By the application of desirability code the different wears of the tools was improved .It was found that depth of cut is the most influencing factor for the life of cutting tools in the case of filament wound pipes where as for hand layup pipes feed rate is the critical factor.

Ghalme et al. (2016) [66] studied machining of GFRP by milling and optimization was done by Taguchi method. It was found that Taguchi method for the optimization of milling operations was very effective technique. Optimized parameters for the milling process was found as speed at number 1, depth of cut at number 2, feed at number 3. ANOVA output showed the contribution of speed as 50% for surface roughness. It was presented that in the production planning and control of the industry the Taguchi method optimization could be successfully used.

Planikumar et al. (2008) [67] studied the turning operations on GFRP polymer using PCD tipped tool. The cutting parameters were optimized using Taguchi and response surface methods. Surface finish was optimized for different cutting parameters of lathe machine. It was found that feed was the number one factor which affects the surface finish of component. Depth of cut had the minimal affect on surface finish. For the turning operation it was observed that upper values of cutting speed, upper values of depth of cut, lower values of feed rates are responsible for good surface finish. Through this developed model time and cost of the manufacturing operation could be saved by predicting the surface finish in advance.

Hsiao et al. (2010) [68] developed model for optimization of table movements quality parameters including damping, displacement, time band, forces viz. by Taguchi and GRA. The requirement of experienced persons to set the variable / parameters of motion tables which was frequently used in laser cutting machine, electronics assembly machines, tables of electric discharge machines has been removed. By this model it was easy to find out the motion parameters such as torque levels movements, time synchronisation. Good agreement between the input parameters and quality response function had been achieved.

Khan et al. (2010) [69] carried out the experiments on high density poly ethylene material produced by recycling in place of fresh material. The parameters of injection moulding machine were optimized using GRA and PCA. It was found that by finding the optimum parameters of temperature, pressure, time of holding and injection. It was possible to design the recycled polyethylene having same compressive, tensile and flexural strength as that of fresh material.

Juang and Tarng (2002) [70] developed model for optimizing the welding parameter to obtain the geometry of the weld having high strength. The geometry of the weld i.e. height and width in the front side and both of them on the back side should be at minimum level to obtain strong welded joint. For this with help of Taguchi optimization design of process parameters including Arc gap, flow rate, current, speed are selected. By the presented approach minimum the better was opted and the optimum values of welding parameters were determined to obtain minimum height and width on the front and back side to obtain high strength joint.

Caydas and Hascalik (2008) [71] optimized the cutting parameters of laser machine by converting multi response characteristics into single grey relational grade. In this power and speed of the laser machine was used as the input parameters and surface finish, width, heat affected zone (HAZ) were taken as quality functions. Sixteen experiments were performed and GRA was used successfully. Validation of the results was done by doing the cutting at optimum parameters to obtain the desired quality functions.

Tsai and Li (2009) [72] worked on the laser machining of quad flat non lead strips having layer of copper and epoxy used for integrated circuits in electronics engineering . This combination is having the challenge of machining two dissimilar materials having machinability of almost opposite nature. However the cutting parameters of the laser machine - frequency, current and speed optimized by the response table obtained through GRA. Three output quality parameters – HAZ, complete depth of cutting, thinner cutting line converted into single grey relational grade and optimum cutting parameters were generated.

2.5 TOLERANCES AND NOISE TESTING

In the gear pairs geometrical tolerances on gear specifications affects the noise and vibration. The overall life of gear box, bearings and shafts get affected by these parameters. Backlash, running clearance, surface finish are the factors which should be precisely controlled to get the quality of gear pair combination.

Senthilvelon and Gnanamoorthy (2006) [73] designed and developed the new operating process for injection molding of GFRP. Observation on the fiber orientation was taken and correlated with shrinkage pattern by mould flow simulation along with that validation was done with the experiments. It was found that results of the simulation and practical results were matching. The overall shrinkage of the gear in the volume decreased due to stiffness of the glass fibers. In the regions of complicated shapes near involute, root showed shrinkage patterns which was uncontrollable.

Dayi et al. (2013) [74] investigated the bending strength of low module gear through modelling by finite number of elements. It was found that during machining of gear tooth, wear of cutting tool was major cause of dimensional variation in tooth thickness and root fillet radius. The variation of tooth thickness and fillet root radius had little impact on noise, vibration in the start but as the power transmission goes on increasing it develop stresses on root which further increase resonance, noise, vibration leading to failure of tooth which further increase the gear shaft, bearing, housing misalignment and had cumulative effect on the overall assembly of gear box.

Yang and Wu (2015) [75] developed model for determination of surface cracks of gears by using PCA and decomposition method. A testing machine was used to find out the different type of failures including working condition, slight tooth wear, teeth breakage, non balancing of gear producing vibrations and noise. When results were classified with the use of PCA and artificial neural network (ANN) precise values were obtained during gear get jammed. The effectiveness of the ANN model was improved by PCA technique.

Chaubey and Jain (2018) [76] focused on WEDM machining for gears and model the parameters to obtain low surface roughness and precise dimensions. It was found that non uniform sparks were responsible for surface roughness. Involute profile deviation, involute profile form deviation, lead deviation, lead form deviation increased with the increase in pulse timing and voltage of spark. It was demonstrated that possibility of manufacturing quality gear exists in WEDM by controlling machining parameter of spark. Controlling root diameter within tolerances was very important as it controls the root stresses, noise and vibration which was achieved by this process.

Garg and Sharma (2010) [77] carried out the study of noise and vibration develop from train and their affect on the nearby buildings and structures. It was found that vibrations and noise emerging from the trains are not strong enough to damage the buildings and structures however this could cause errors in sensitive measuring instruments in nearby area. Noise and vibrations could cause loss of efficiency of people in nearby area. This could be avoided by using damping instrument or trenches isolating the railway tracks and other vehicles movement area. It was found that with the increase of transportation due to increase in population, the level of noise and vibration emerging from trains and transportation means is also increasing so there was requirement of developing anti vibration and noise control systems.

Senthilvelon and Gnanamoorthy (2006) [78] studied dimensional variation of selective gear teeth of dissimilar polymer and composite materials. In this research CFRP was used in the tooth profile region whereas in the hub region standard polymer (Nylon 66) was used. To study the dimensional failure in between the interface of two dissimilar materials joined by two methods, torques had been applied. First was the circular bonding second was the spline formation between hub and tooth region. Single piece CFRP gear and assembled CFRP with nylon66 gear showed same life in fatigue.

Xiao et al. (2017) [79] designed and developed model for finding out the capability of shaft, bearing and housing to transmit the vibration, energy due to impulse produced by impact on gear. In this the acceleration with impact force, time duration, amplitude, and gear speed had been correlated. It was found that ratio between vibration and dissipation of energy was within the limits. The maximum noise was occurred in between the inner race of bearing to the outer race of bearing and was minimum at outer race and housing of the gear box. It was the time period of impact force which decides the magnitude of rattling and vibration of the gear box. It was found that micro gap in between the inner race and outer race contributes to 60% and micro gap between gear and shaft contributes to 40%.

Jolivet et al. (2015) [80] designed and developed the multiscale analysis to find out affect of surface integrity of gear teeth on the unstable noise in gear box. The experiments were performed on gears whose teeth were grinded in first case and honed in the second case. Through this approach it was possible to find out the frequency of vibration arises in gears come from different finishing processes. It was possible to discriminate the vibration and noise arises from the gear box or surroundings. The vibration and noise generated from honing is less in comparison to grinding.

Dion et al. (2009) [81] studied on the noise generated by impact of transmission gears and idler gears in the gear box. The features responsible for the idler gear noise had been highlighted. The parameters responsible for noise were reduced in less number and some of them were converted into without dimensions to simplify the complex problem. Different experiments were performed to find out the variation in same set of parameters. It was found that impulse force come from side of rotation. The misalignment of the shaft governs the side of impact of vibration and noise. The affect of force depended on rise and fall in speed of gear.

Palermo et al. (2018) [82] related the noise, vibration, harshness of the gear with mismatch of gear engagement and disengagement during running. To find out the error comparison between precision testing machine in the laboratory and testing machine at manufacturing workshop was done by loading the test gears. First one was used to measure noise in gears with use of electronic encoders and second was used to measure gear box of battery car. Laboratory gear box was found to be more precise and accurate than factory testing machine. More speed range, low cost, sensitivity to higher tolerances was the dominant features of laboratory testing machine.

Senthilvelon and Gnanamoorthy (2006) [83] studied the variation of root fillet radius on the strength of injection moulded spur gear. It was found that for more values of fillet radius surface integrity of tooth reduces at the pitch region and for low values of fillet radius root cracking of the tooth was more at the root circle diameter. A power absorption testing machine was used to check the effect of dimensional variation took place due to bending of polymer gear at roots having different fillet radius.

Kamps et al. (2018) [**84**] conducted the experimental study on gears manufactured by beam of laser machine to save the price and energy during manufacturing. The developed model was executed on industrial gear and quality variation checked for 12 gears. It was found that quality and cost was comparable with milling and hob forming process of gear. Initial cost of equipment was high whereas for consumable tools were 4% of conventional manufacturing cost.

Klocke et al. (2011) [85] described the surface integrity of the tooth generated by hob cutters. Studies were made on outlook of the machined surface and methods that could be adopted for eliminating defects. Hob cutting of the gear was performed without the application of cutting fluid. The two visible defects were sticking of the microchips on the surface of tooth and scratched surface. Parameters like cutting length, angle of clearance and micro size of the chips were optimized to obtain good surface finish. The research targeted on tooth then to focus on whole process.

Domek et al. (2014) [86] investigated the mechanism of gear used in measuring instrument along with belts. Tolerance related to the geometry was analyzed in this research. In this the gear and shaft was considered as different circle and cylinders, arrange along the axis of shaft and gear. Out of order of these surfaces affects the effectiveness of the gear in torque transmission. Error was associated with transmission of the power from surface of gear to the surface of timer belt. These were utilised in controlling the time and measurements system. It was found that surface area coming in contact, intended function mismatch, stress localization, variation in friction due to different preloading accounts for variability in load transfer and overall effective life of timer belt gear.

Brecher et al. (2016) [87] presented model for predicting the machining pattern of angular gears in order to obtain silent behaviour and good load carrying capability within the gear box. In this by finite element analysis surface contact of all the teeth with this geometrical variation are simulated on the software and tested on the machine, results were in good agreement. By lapping followed by grinding increase the surface contact area during rotation and resulted in low noise, increased life, lower bending, lower surface stresses. Tooth stiffness data measured after application of force showed mismatch of power transmission at the pitch circle diameter was responsible for noise.

Rodionov and Rekadze (2017) [88] proposed the new process to find out noise and vibration of polymeric materials in pump made up of gears. In this data was collected for gear rotors of different polymeric composite materials. A cover was used having isolation of noise and vibration, it was found that maximum noise level go up to 76 dBA. Noise level in totality for PA material was less than PEEK. It was found that the elastic modulus between polyphenylene sulphide and PA having difference of around 2 times but difference in their noise level was very low. It was found that soft materials have low noise and vibration when used as gears.

Haggstrom et al. (2018) [89] conducted the study on dimensional, geometrical tolerance of gears during machining and related it to thermal, mechanical load excitation. Finite element analysis model has been developed to find out tolerance, its affect on load carrying capability of gear in practical application. It was found that in trucks roundness deviation of the bevel gears contributes to major cause of thermal and mechanical force. Errors rose from manufacturing deviations accounts for noise, vibration in application. Developed model related the gaps between tolerances, costing and life of gears.

Senthilvelon and Gnanamoorthy (2008) [90] analyzed shrinkage affect of 20% glass fibre on the dimensional and geometrical tolerances of the gear which further affect the involute, form, lead, teeth spacing, run out of component. It was found that glass fiber at the surface of tooth worked as the wall and avoids shrinkage on the involute shape of gear in comparison to the unreinforced gear. It was observed that glass fiber Orientation not following the path of width of tooth so shrinkage problem arises along the width resulting in lead error. Since glass fiber were hard in nature and available at the surface of teeth resulting in improper form/shape for lead and involute. Thickness of the teeth, spacing between the teeth, run out along the diameter in the case of GFRP was more in comparison to material having no glass fiber due to presence of uneven fibers on the surface.

Mao et al. (2015) [91] used special machine having three integrated operation including turning, milling, hobbing for gears. Developed machine could be able to manufacture the gears within the range of 7.5 μm. Tolerances of the gears generated were equivalent to the precision obtained from the machines available in market but in which turning, milling, hobbing operations had to be performed independently. Controlled profile was responsible for low noise, vibration and low root stresses during the power transmission in small machines and gear boxes.

Guillermo et al. (2018) [92] developed a model for predicting the life of gear in surface failures and failures arises below the surface of tooth. By using this approach the service life of gear could be enhanced as two areas were optimized simultaneously first was the top surface and second was surface below the layers of top surface. This innovation could open new dimensions in special coat on surface, heat treatment process, case hardening etc. Presented method leads to the research areas like lubrication affect, compression, tension, and shear at the surface layers. This methodology aimed at joined affect of gear with shaft and bearing on noise, vibration, harshness of the atmosphere.

Kalin and kupec (2017) [93] used temperature as the governing parameter in life of polymer gears. A test rig had been developed to vary load and temperature. It was found that if root temperature of the tooth could be controlled it could run for more number of cycles. The change in temperature affects the life and load carrying capability of gear to a great extent. It was found that up to four times life of polymer gear could be enhanced just by controlling the temperature. Increment in temperature was responsible for decreased effectiveness and efficiency of the gear box.

Benedetti et al. (2017) [94] presented the relationship between surface coating of worm gear on life of the gear box. In this a model has been developed to find out the coating thickness with different material variants and their affect on noise, vibration of gears. Load of the gear in tangential direction could be used as route for development of worm gear boxes. Small pits arose on the surface in case of tungsten coating after same number of cycles of operation governs better life in comparison to chromium coating. Plasma treatment on surface of worm gear showed low life when loss of weight taken as governing criteria.

Xu et al. (2015) [95] developed a model to calculate the deviation of tooth profiles by rotation of the gear axis. A sensor based machine used probe made up of diamond to evaluate the involute profile of spur gear. The run out of the gear along pitch circle diameter had been taken. Calibration of the measurement system was done in such fashion that the error in forward and reverse direction of motion nullifies each other. For validation of the results a tested gear loaded on the spindle and compared with results of test gears. Measurement when repeatedly taken shows very little error within the range of 300 nanometre.

Jolivet et al. (2016) [96] investigated surface roughness of gear tooth and developed a model to relate it with noise and vibration. The study of the surface was done on micro level with and without the application of lubricant. It was found that vibration and noise develop at micro level from minute surface roughness would have cumulative and accelerated effect on wear life of gear. The addition of lubricant between the mating surfaces could reduce noise, vibration but it would be better to study the deviations considering wet transmission.

Evans and Keogh (2016) [97] developed a model for the prediction of efficiency and power losses in the meshing of steel, polymer gear. An analogy of heat generated during friction of rod made of steel on disc made of polymer was done and associated with friction generated due to slipping between tooth mating surfaces during torque transmission. Data collected from these two methods were collected and a variation of about 9% was found which was due to variation in dimensional and geometrical tolerances came in manufacturing processes of teeth of gear. When the test steel rod has inclination on polymer disc, data collected and compared with theoretical model and was found within the limit.

Ene and Dimofte (2012) [98] presented a model for predicting the noise and vibration when bearing surfaces have inclined shape along with effect of lubrication for compensating resonance. A comparison between the data gathered from two types of bearings in gear box revealed there is reduction in noise of about 17 dBA for defined torque, rpm level. For particular rpm, power rating a noise reduction was about 10 dBA in lubricated gears. Data gathered from experiments when related with theoretical model noise reduction was found. New methods were also proposed to improve the noise for higher magnitude of torque transmission.

Sun et al. (2018) [99] explored the precision and effectiveness of gear hobbing process by developing a model in which experiments performed was found in close agreement with theoretical data obtained by the programme. It was found that new model developed had better results on previous model data when compared with experimental findings. The optimized cutting parameter demonstrated lower dimensional and shape tolerance variations. The efficiencies of the proposed model could be increased by employing more number of cutting parameters and more shape tolerances in multi optimization platform.

Ghosh and Chakraborty (2016) [100] presented the study on the shape of involute to reduce noise, vibration, harshness of the gear box. The noise and vibration data obtained at various time intervals for a fixed speed and different values of speed at particular time interval were analyzed, data obtained revealed the need of profile correction to improve efficiency. It was found that when load varied from one level to another there was slight variation in noise but the small variation in shape of profile had sever affect on noise, vibration. The speed of rotation of gears was directly proportional to profile correction. With increase of profile correction at higher speed noise and vibration had increased.

Fietkau and Bertsche (2013) [101] Investigated the effect of lubrication on noise of gear and consequences on shaft, bearing, housing tolerances. The model revealed correlation between time, shape of profile on film of lubricant between mating surfaces. The model was equation based and related with film thickness, deformation of gear tooth. In addition to gear tooth model integrated bearing, shaft housing, structure and could predict cumulative effect of subassembly as whole. Experimental setup included two shafts with pinion- gear combination. Rattling sound and whining sound levels were optimized by controlling speed and geometrical tolerances.

Efstathiou et al. (2012) [102] attempted the study to find out shape tolerances for gears used in operation model of ancient gear based computer. The research was done in three areas, first was determination of measures of all the gears used in mechanism second was finding out fillet root radius, pressure angle, module and length of chord and third was centre distance between all the gears used in the mechanism. By using this traditional equation along with latest techniques it was possible to develop highly precise and functional gear motion based computer.

Jabbour and Asmar (2015) [103] studied the characteristics of gear tooth when running along the axis and when running at angle with axis of gear. In this method distribution of forces was done along the line of transmission at pitch circle diameter. In case of inclined tooth it was differentiated into large number of spur gears. Results obtained were validated with finite element method. Measurement of stresses at different speed data obtained was complicated and demonstrated points at which contact stresses were critical. It was found that in case of spur gear with the increase of number of teeth fillet root stresses increases. In the case of helical gears maximum value of fillet root stresses located at 1.65 times normal module and surface stress located at radius of pitch circle.

Bozca (2018) [104] investigated the geometrical tolerances of spur gears to reduce the noise and vibration in gear box. It was found that module, size, teeth numbers and clearance between gears are directly proportional to noise and vibration level. It was demonstrated that profile correction in positive direction reduce noise and vibration level. It was confirmed that error in the geometrical shape directly proportional to noise and vibration level. Precise and accurate forming of gear tooth within tolerance bands could be able to reduce disturbance. By optimizing size of module, gear ratios and space between mating teeth reduces noise and vibration.

Theodossiades and Rahanejat (2015) [105] carried out the study to understand the performance and noise generated in air by lubricated gear pairs which was running ideally. The theoretical and practical results were obtained on gear pair related to quality and quantity. It was found that vibration caused by idler gear increase shaft torsion responsible for overall noise of gearbox. It was depicted that matching and mismatching of frequency of vibration of different gear pairs in gear box could add or reduce magnitude of sound levels. Thus through this model it was possible to design the transmission systems for reduction in sound levels.

Wiemann et al. (2018) [106] noted the surface characteristics of big module gears and developed a machine to measure the dimensional and geometrical tolerances. It was found that the measurement results were in uniformity with calibrated measurement techniques and could be used to find out the dimensions. Geometrical variation and correction in the manufacturing practices could be related with noise in the study. In this tracing method of variation of tolerances was adopted to diagnose root of error than correction was implemented at designing and manufacturing phase.

Haefner et al. (2018) [107] investigated the tolerances of gears having module of less than 200 at micrometer level. A model was developed to calculate the deviations in shape of involute profile and there resultant tooth stresses. In order to reduce the number of experiment technique of ANN was used to obtain data related with tolerance zone of spur gears. With the help of this model it was possible to maintain the quality of small module gears used in medical machines.

Hoskins et al. (2011) [108] revealed the affect of speed on polymer gear noise. It was found that surface finish of gears accounts for noise in polymer gear due to their sticking behaviour. The noise level of polymer gears found to be inversely proportional to the rpm of gears on the other hand it was directly proportional to rpm and applied torque for other gear materials. For all the materials of gear the surface finish advocates for noise and vibration level. Surface wear of tooth face was directly related to noise and vibration.

Karpov et al. (2017) [109] studied the fatigue performance of gears for modified tooth. It was theoretically find out that a small modification of profile during hobbing process can reduce the noise, vibration of gear pair up to high magnitude. Attachment for hobbing had been developed to machine the profile at located points where modifications could have diminishing effect on resonance. Studies revealed that machines in which gears with speed variation are required could go for involute teeth having profile modified from circle.

2.6 RESEARCH GAPS

- From the review of existing literature it is apparent that many studies have been carried out on load testing of gears. Critical quality responses of gears including life of gear tooth, root stresses, failure mechanisms, surface strength, material alterations affects have been studied through test rigs, on site testing and computer assisted analysis software's. To accomplish this different combinations of parameters have been framed for various quality requirement.

- In the present scenario noise, vibration, light material, lubrication, load carrying capacity, gears showing accurate dimensional / geometrical tolerances is the requirement. To achieve above requirements one or the other way quality combinations was lacking. It was found that polymer composite gears were having the properties to suit modern engineering requirement but forming process of these materials to inculcate the power transmission application needs to be addressed.

- It is found that composite polymer gears in single step are fabricated by injection molding technique, which has the shrinkage problems resulting in transmission errors. So the literature related to machining of the polymer composite was studied. It was found that by altering machining parameters like cutting speed, feed rate, depth of cut, tool materials, use of cutting oils-surface finish and tolerances could be changed. It was also found that by varying reinforcement ratios, matrix materials, bonding techniques-quality of machined surface/subsurface could be changed. Vast literature was available for machining of polymer matrix composite (PMC) in the area of turning, milling, drilling etc but no studies were available for tooth generation in PMC gears by machining.

- Literature survey related to optimization of input parameters to provide various techniques related to it are available but these give results which were variable from application to application. It was found that these techniques greatly reduced number of experiments. Firstly Taguchi and GRA to optimize multi response quality characteristics secondly RSM for single quality response variable gives best results but its implementation was on different application. Therefore in present study these techniques are applied on optimization of gear applications.

- Literature survey related to tolerances and noise testing, it can be concluded that tolerances in gears and other mechanism related closely to noise. As tolerances must be given in assemblies but their limits must be precisely controlled to arrest noise. These were checked through test rigs and analysis software's. Noise analysis for the gears after shot peening performed on metal matrix gear pairs .It was found that root fillet radius for fine pitch gears were not defined and needs to be optimized to have control on noise. In the present study noise of the gears made up of MMC, GFRP and steels were compared which was lacking in literature survey. The affect of fillet root radius deviation on stresses, deformation and strain is studied on MMC which was compromise in between light weight and strength of polymer – steel range.

2.7 OBJECTIVES AND SCOPE OF THE PRESENT WORK

Based on the literature survey, the performance of composite gears is to be enhanced so that it may be used in place of conventional steel for various engineering applications. Therefore the present work aims to analyze the performance of composite material gears. The above goal has been achieved by the following research objectives:-

(i) To prepare the GFRP, MMC material blank and analyze the quality of spur gears made by gear shaping process.
(ii) To fabricate, mold and fixture for obtaining the gear blanks and machining on gear shaper with different cutting parameters.
(iii) To study the effect of various machining parameter on root diameter deviation (RD), tooth thickness variation (TT) and Surface roughness (R_a).
(iv) To evaluate the effect of various process parameters and shot peening on surface integrity, noise and vibration on gear performance during running.
(v) Gear design through structural analysis.

2.8 SUMMARY

It can be concluded from review that polymer composite gear is commonly used in power transmission due to light weight, silent running but mostly manufactured from injection molding which has inherent problem of shrinkage. However no attempt is available in the recent past to manufacture these gears through molding and machining. It integrate the double benefit of light weight and close tolerance control. The combined approach of injection molding at first step and machining in second step improves life and noise of GFRP gears. The novelty of the current work depicts the optimization of gear shaper machining parameters to have control on root diameter deviation, tooth thickness variation and surface finish. Apart from above the present work demonstrated the affect of shot peening on improvement of MMC gear hardness. Present research optimized the fillet root radius of fine pitch MMC gear to avoid undercutting.

CHAPTER 3

EXPERIMENTAL SETUP AND PROCESSES

3.1 INTRODUCTION

As mentioned in previous chapter GFRP gear has the unique properties of low noise, light in weight, damping properties in comparison to steels, MMC and other materials. Injection molded spur gear has limitations of shrinkage, which leads to geometrical errors. In present novel approach, gear blanks are produced by injection molding and finished gear is obtained from gear shaper machine. In the case of gears surface roughness and geometrical tolerances needs to be controlled that may be accomplished by optimizing the gear shaping parameters.This chapter describes the preparation of material, experimental setup for gear shaping, selection of process parameters, Taguchi method, GRA procedure for multi response optimization, RSM for surface roughness optimization, test rig for comparison of noise - damping, method of fillet radius optimization through Ansys-CAD model.MMC and GFRP gear could replace steel gears where torque is of low value. These composite material gears offers low weight with high strength. As well as are less noisy and corrosion resistant. The usage where cost is not the criteria MMC gears could be replaced with steel gears. Otherwise GFRP gears could be used in place of steel gears. The mechanical properties of AISI 4140 steel are ultimate tensile strength of 1020 MPa, Yield strength of 655 MPa and izod impact strength of 22.6 J under normalized condition [110]. AMC225XET4 aluminium silicon carbide MMC extruded bar having ultimate tensile strength of 690 MPa, yields tensile strength of 487 MPa and fracture toughness of 20 MPa-$m^{1/2}$ [111]. Zytel 70G33L NC0110 GFRP is having stress at break equal to 200 MPa, notched charpy impact strength at 23 degree centigrade equal to 13 KJ/m^2 and unnotched charpy impact strength at 23 degree centigrade equal to 85 KJ/m^2 [112].

3.2 PREPARTION OF MATERIAL

In the comparative analysis of MMC and GFRPs the later is produced by injection molding process and former is prepared by stir casting process. One is polymer based composite material and second is metal based composite material having reinforcement of ceramics. Glass fibers are added in polymer matrix as reinforcement and silicon carbide are added in aluminium matrix. Both are light in weight than steel. In between GFRP and MMC, GFRP gears are lighter and generate less noise in comparison to MMC gears due to presence of polymers.

3.2.1 Glass fiber reinforced polymer

GFRP could be fabricated by two methods. First one is glass fiber are laminated with polymer and second one is granules of polymers mixed with glass fibers could be taken. In present case second method is selected in which GFRP in the form of granules are selected.

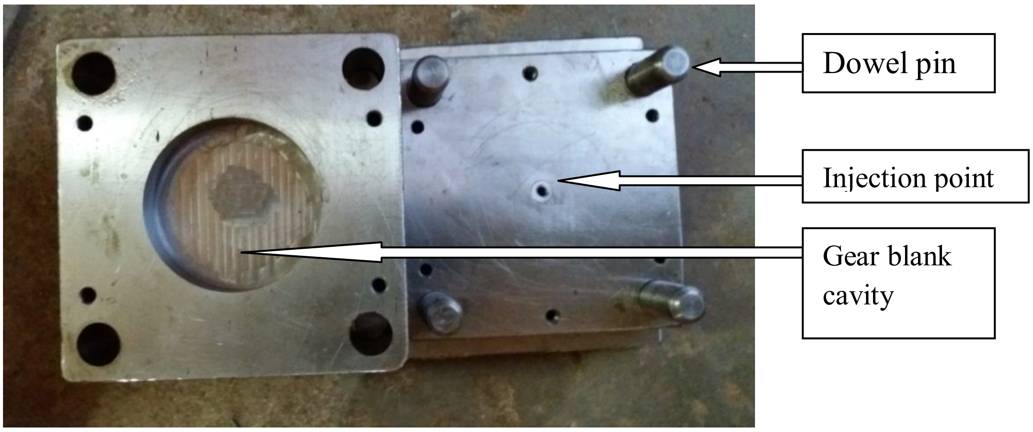

Figure 3.1 Mold for GFRP gear blank

Engineering polymer of DuPont make Zytel 70G33LN010 with 33% glass fiber reinforced polyamide 66 resin has been chosen for making gear blanks detail of its properties are given in Table 3.1.

Table 3.1 Mechanical Properties of GFRP

S. No.	Particular	Value
1	Density (Kg/m^3)	1390
2	Stress at break (MPa)	200
3	Tensile modulus (MPa)	10500
4	Poissions ratio	0.39
5	Notched impact strength (kJ/m$^{2)}$	13
6	Un notched impact strength (kJ/m^2)	85

These granules are dried and put in the hopper of injection molding machine, heated and melted in semi solid form then injected into the mold cavity as shown in Figure 3.1. The mold is prepared on vertical machining center. In present case blank having diameter of 102 mm x 22 mm is prepared taking shrinkage into consideration.

Figure 3.2 Gear blank after injection molding

3.2.2 Metal matrix composite

In MMC as steel gears has to replace with light weight composite material so aluminum alloy LM6 (consisting of 0.1% max copper, 0.1 % max magnesium, 10-13 % silicon, 0.6 % max iron, 0.5 % max manganese, 0.1 % max nickel, 0.1% max zinc, 0.1 % max lead, 0.05 % max tin, 0.2 % max titanium and aluminum remainder) has been taken as matrix material and silicon carbide particles of 300 mesh size, 10% reinforcement ratio has been taken and produced by stir casting process. In stir casting process aluminum has been heated up to temperature of 900 degree centigrade to molten state in ladle.

Silicon carbide particles has been preheated at temperature of 900 degree centigrade separately and mixed with molten aluminum. The mould is made by mixing coal dust, sand and bentonite. 0.5 % magnesium is added to the molten aluminium LM6 alloy to decreases the viscosity of aluminum alloy. As density of silicon carbide is higher than aluminum it tries to settle down to avoid that it is stirred in molten state and allowed to cool down in sand mould during stirring is going on, so that reinforcement particles trap in matrix material.

Figure 3.3 MMC blank after stir casting

As shown in Figure 3.3 casting of MMC obtained from sand mould.Finally blanks are obtained from lathe machine for teeth cutting on gear shaper machine.

3.2.3 Gear preparation

These solid blanks are clamped on three jaw chuck then turning, facing, boring operations are performed on Kirloskar make Lathe machine. The outside diameter of 100 mm and bore of 47 mm is controlled within the run out of 0.02 mm.The finished gear blank is mounted on the vertical mandrel of HMT (Hindustan Machine Tools) make gear shaper model S150 to cut the teeth as shown in Figure 3.4.Run out of the work piece is controlled and checked for 20 µm on the fixture with help of dial indicator. It is properly clamped with 30/32 double ended spanner and butting of face of blank on fixture face is ensured before cutting teeth. The cutter used is of 50 teeth, 2 module.Material is high speed steel having 18% tungsten, 4% chromium, 1% vanadium as alloying element. It is properly mounted on the gear shaper spindle. The cutter is having reciprocating motion along with rotation on its axis so that all the cutting edges are used. Finished gear specimen after cutting is shown in Figure 3.5.The dimensions for the gear are chosen as number of teeth 48 module 2 mm and detailed specification are given in the Table 3.2

Figure 3.4 Gear shaper machine

Table 3.2 Specification of Spur gear

S.No.	Description	Formula	value
1	Number of teeth (numbers)	z=d/m	48
2	Module(mm)	m = d/z	2
3	Addendum(mm)	h_a=1m	2
4	Dedendu(mm)	h_f=1.25m	2.5
5	Pressure angle	Degree	20
6	Tooth thickness(mm)	t = 1.6m	3.2

7	Tooth height(mm)	$h= h_a+ h_f$	4.5
8	Face width(mm)	W=5m	10
9	Pitch circle diameter(mm)	d = mz	96
10	Root diameter(mm)	$d_f= d-2 h_f$	91
11	Outside diameter(mm)	$d_a =d+2 h_a$	100
12	Base circle diameter(mm)	$d_b=d \cos \alpha$	90.21

Figure 3.5 Finished GFRP Spur gear

3.3 PROCESS PARAMETERS AND LEVELS

Table 3.3:- Process parameters and their levels.

Process parameters	**Parameter Designation**	**Levels**		
		L1	L2	L3
Rotary feed (mm/stroke)	F	0.15	0.17	0.19
Cutting speed (stroke/min)	S	180	210	240
Fluid ratio (percentage)	R	4	8	12
Fluid flow rate (ml/min)	FR	25	30	35

Table 3.3 shows four parameters and three levels. The range of process parameters are selected based on pilot experiments.

In the case of gear shaper feeding of the uncut surface of gear blank take place through rotation of blank in horizontal plane and cutter reciprocates in vertical plane.

Rotary feed depicts new uncut material in millimeter which come in contact with cutter in each stroke referred as mm/stroke.In the gear shaper rotary feed controls the rotation of gear blank in front of the cutter as the rotary feed decrease the number of cutter strokes per teeth increases. It means cutter passes through the un machined surface repeatedly and the surface which remains uncut get cut due to the overlapping of the cutter stroke. The rotary feed (F) is controlled by the help of change gears in the gearbox one gear is attached with cutter and controls the rotation of cutter and one is attached with the table controls the blank rotation.

The cutting speed (S) i.e. strokes per minute is controlled by changing the V- belts mounted on motor shaft and drive shaft.It indicates the rate at which material is removed from the blank. The water soluble cutting fluid chosen is Servo cut S of Indian oil make different ratio (R) is used for good surface finish. Flow rate (FR) is controlled by lever mounted on the outlet of pump, as the requirement is chips get quickly wiped out from cutter- work piece interface to obtain low surface roughness.

3.4 QUALITY PARAMETERS OF GEAR

Surface roughness (R_a), Root diameter deviation (RD) and tooth thickness variation (TT) are taken as quality control parameters. R_a of tooth affects the noise, vibration and load carrying capacity.

RD deviation affects the root fillet radius and is responsible for tooth beam strength. TT variation controls the proper meshing of teeth and responsible for noise, vibration.R_a affects the friction and life of teeth in wear [113].

The gear after manufacturing is measured for RD deviation on profile projector, model ICON 300-make Meera Metzer as shown in Figure 3.6. Gear is placed on glass table, projected light beam produce the profile of teeth on screen, with the help of vertical and horizontal graduated lines the maximum value of root diameter is measured.

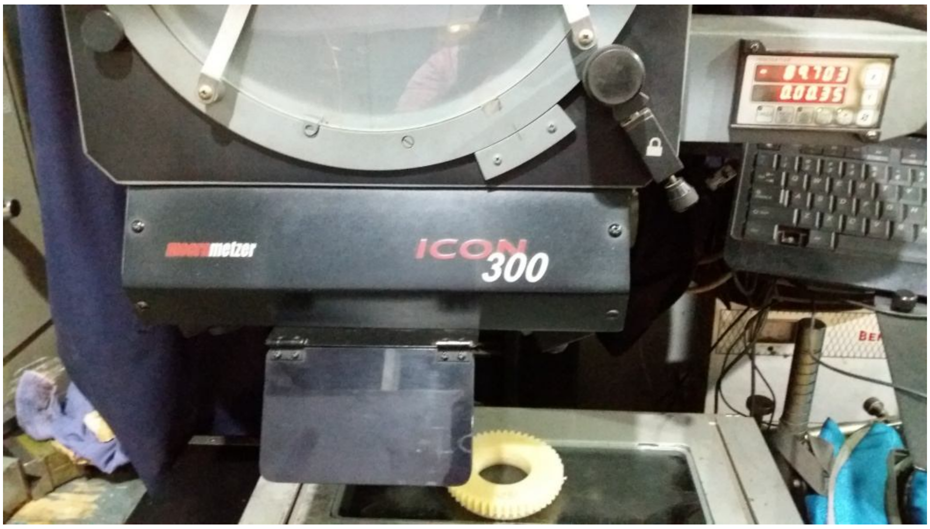

Figure 3.6 Profile Projector

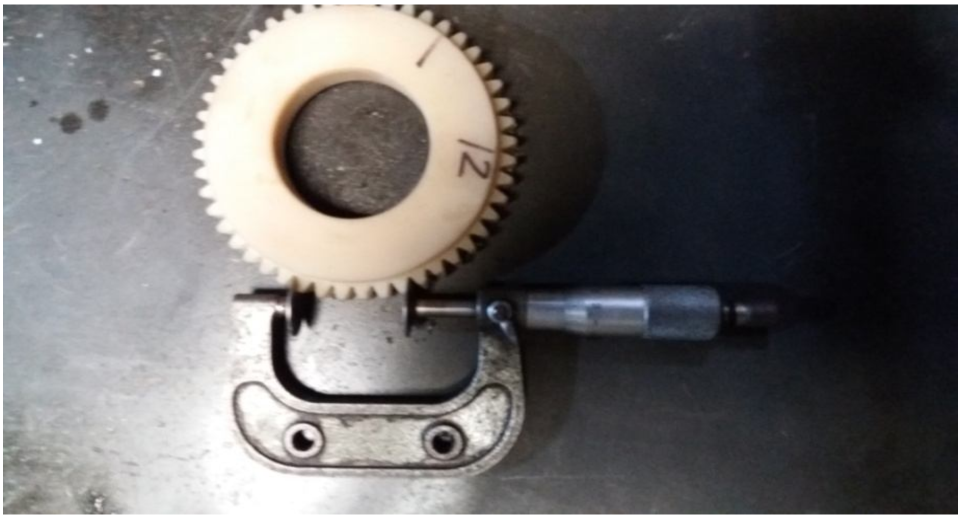

Figure 3.7 Micrometer

RD deviation is calculated from subtracting measured reading of profile projector from average value.It is obtained by dividing the upper limit of 90.8901 mm and lower limit of 90.7802 mm by 2. Its value is 90.8352 mm as per DIN standard 867.As per DIN 867 standard base tangent length for 2 module, 48 teeth over five teeth is having upper limit of 27.8761 mm and lower limit of 27.8385 mm respectively. The average value is calculated by adding these two limits and dividing by 2. The average value obtained is 27.8573 mm. Tooth thickness variation is obtained by subtracting measured value from average value.

Figure 3.8 Surface roughness tester

TT variation is calculated by first measuring the base tangent length over 5 teeth with the help of disc micrometer (Mitutoyo, 25-50 mm) as shown in Figure 3.7. The gear is placed on surface plate, 5 teeth are measured with fixed disc/movable disc by gently rotating the ratchet screw.

The average R_a is measured by using the Mitutoyo make Surftest SJ-301 instrument shown in Figure 3.8. As the teeth is smaller than stylus of tester. So the teeth is first cut from the gear, placed on surface plate. Then stylus is allowed to move in perpendicular direction to machined surface direction as the surface roughness is maximum in this direction. Stylus is moved along the scan length of 4.5 mm which is the tooth height of gear.

3.5 GREY RELATIONAL AND TAGUCHI TECHNIQUE

GRA and Taguchi analysis is a technique, in which multiple performance characteristics is converted into single grey relational grade then responses are judged, validated with ANOVA as shown in Figure 3.9.

Hence, the present study considers optimization of RD deviation, TT variation and R_a. Using Taguchi orthogonal design with four process parameters viz. rotary feed, cutting speed, cutting fluid ratio, cutting fluid flow rate. The test results are analyzed for optimal combination of process parameter as predicted by Taguchi and grey relational method [114, 115 and 116].After that Analysis of variance (ANOVA) is carried out to analyze the effect of process parameters and their interactions on the performance characteristics of the gears [117].

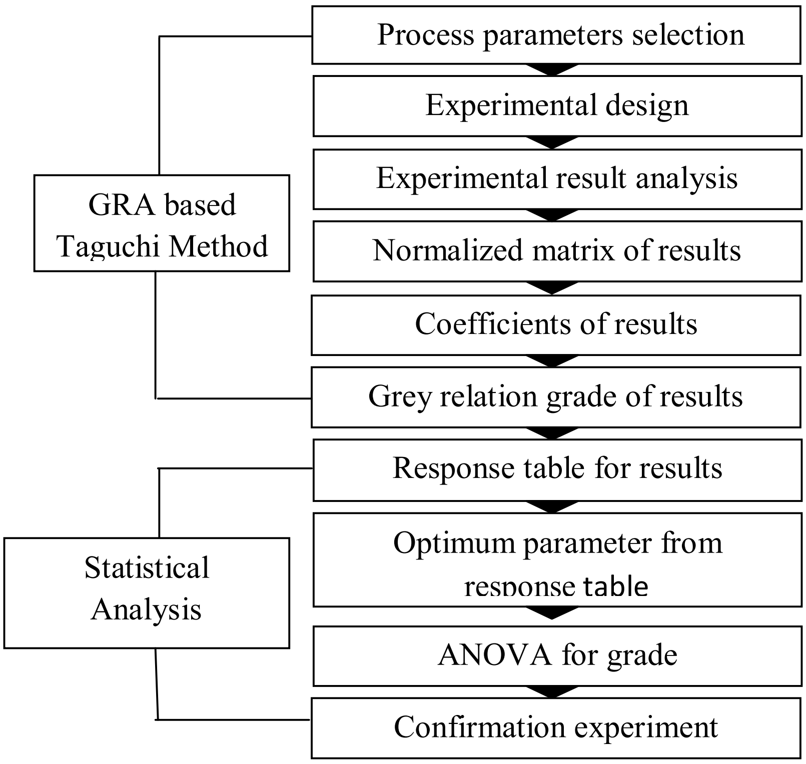

Figure 3.9 Flow chart for analyzing performance characteristics

3.6 GREY RELATIONAL ANALYSIS BASED TAGUCHI DESIGN

The orthogonal array is a full or fractional factorial matrix that gives adequate comparison of levels of the process. In the present analysis an L27 orthogonal array is used [118, 119 and 120]. GRA is a technique that can be used for decision making of multiple attribute [121]. In GRA the experimental results of RD deviation, TT variation and R_a are normalized in the range between zeros to one. The data for RD deviation, TT variation, R_a is minimized and expressed as:

$$x'_i(j) = \frac{max_j y_{ij} - y_{ij}}{max_j y_{ij} - min_j y_{ij}} \quad (3.1)$$

Then a normalized matrix is obtained by equation 3.1. From the normalized matrix a reference value is generated using equation 3.2. Which is the largest value of normalized value for each entity.

$$x'_0(j) = max^n_{i=1} x'_i(j) \quad (3.2)$$

The next step is to make the difference matrix by subtracting normalized entity from reference value through equation 3.3.

$$\Delta_{oi}(j) = \left| x'_0(j) - x'_i(j) \right| \tag{3.3}$$

Then, the grey relational coefficients are find out using equation (3.4).It shows the relationship between the desired and actual experimental values

$$\delta_{oi}(j) = \frac{min_{i=1}^{n} min_{j=1}^{m} \Delta_{oi}(j) + \zeta \times max_{i=1}^{n} max_{j=1}^{m} \Delta_{oi}(j)}{\Delta_{oi}(j) + \zeta \times max_{i=1}^{n} max_{j=1}^{m} \Delta_{oi}(j)} \tag{3.4}$$

Where ζ $(0 \leq \zeta \leq 1)$ is known as the distinguishing coefficient .If the value of ζ is small there will be more distinguish ability. In most cases, ζ takes the value of 0.5 because this value usually gives slight distinguishing effects and good balance.

After this a weighting method is used to find out the grey relational grade for every experiment. This grey relational grade is the value which shows the optimization of multiple performance characteristics.

$$\gamma_{oi} = \frac{1}{m} \sum_{i=1}^{m} \delta_{oi}(j) \tag{3.5}$$

The grey relational grade is obtained through equation (3.5) while considering the same weight age for performance characteristics i.e. 1. In equation (3.5), m is the number of performance characteristics.

The best group of process parameters for optimum performance is determined from response table by Taguchi analysis. The optimal grey relational grade γ_{opt} is obtained by following equation:

$$\gamma_{opt} = \gamma_m \sum_{i=1}^{n} (\gamma_i - \gamma_m) \tag{3.6}$$

Where γ_m is the average of grey relational grade, γ_i is the average of grey relational grade at optimum level and n is the number of affecting process parameters. ANOVA table and response table are formulated from MINITAB [122].

3.7 RESPONSE SURFACE METHODOLOGY

RSM is a collection of statistical and mathematical technique which is used for the modeling and analysis of problems in which interested response (surface roughness) is influenced by the variables (cutting parameters) and the target is to obtain the minimum surface roughness by selecting the optimum parameters

In mechanical applications there is a relationship between an output (surface roughness) and a set of variables (cutting parameters). If we denote output variable by x and cutting parameters by y_1, y_2, y_3,y_4 …….,y_n .If there is a relationship between x and y .Then a model can be written in the form given in equation (3.7).

$$x = f\,(y_1,y_2,y_3,y_4 \,\ldots\ldots, y_n) + z \tag{3.7}$$

Where z represents noise or error observed in the response x. Then we denote the expected response as equation (3.8).

$$E(x) = f(y_1,y_2,y_3,y_4 \,\ldots\ldots, y_n) = x' \tag{3.8}$$

Then the surface represented by equation (3.9) is known as the response surface.

$$x' = f\,(y_1,y_2,y_3,y_4 \,\ldots\ldots, y_n) \tag{3.9}$$

So the first step in response surface methodology is to find a suitable approximation for the functional relationship between x and set of independent cutting parameters. In most cases second order model is used in response surface methodology.

3.8 NOISE MEASURMENT

Noise measurement setup includes a pair of gear having number of teeth 24 and 48 respectively. Both gears mounted in housing having ball bearings and mounted on aluminium plate as shown in Figure 7.1, chapter 7. With the help of sprocket and chain mechanism, gears could be run with the help of electric motor. It is having an electronic circuit by speed of gear could be changed.

Speed could be checked with non contact tachometer. AISI 4140 steel, MMC reinforced with silicon carbide particles and GFRP spur gear pairs have been selected for noise measurement. MMC material is prepared by stir casting method in which sic particle are preheated and mixed with molten aluminum then allowed to cool while stirring is going on till it get solidified into MMC gear blank.

3.9 DEVELOPMENT OF COMPUTER AIDED DESIGN MODEL

A finite element analysis model has been developed, in which by putting the different value of tooth fillet radius: the Von-Mises stress, strain, deformation can be obtained from ANSYS work bench through finite element analysis. Factor of safety for spur gear can be calculated. MMC has been taken as a gear material to develop a finite element analysis model. It is followed by the investigation of effect of tooth fillet radius variation on stress, strain, deflection and factor of safety.

The proposed model is constructed by taking the module, number of teeth and face width as fundamental specification.Detailed dimensions includes addendum, dedendum, pressure angle, tooth thickness , pitch circle diameter, outer diameter, root diameter, base circle diameter and circular pitch.

Undercutting is the phenomenon which occurs when dedendum is large enough to extend below the base circle resulting in profile which is not an involute at the fillet radius. This can be avoided by limiting the minimum number of teeth to 17 for the pinion with 20^0 pressure angle. The fillet radius which is generated automatically due to the cutting motion of cutter is known as trochoidal fillet. Its value is defined as 0.3 times module for coarse pitch gear and for fine pitch gear its value is not defined.

After making the two dimensional drawing, in proE → exit workbench → go to solid modelling; give the pad command for creating the solid model; this model is imported to ANSYS workbench by file → import → IGES.

3.10 SHOT PEENING OF COMPOSITE MATERIAL GEAR

Tensile stress gets developed in gears and shafts after machining which results in its premature failure during use. After shot peening this tensile layer gets replaced by the compressive layer which increases the fatigue life of this power transmitting component. The shots create dimples on the surface and retract back. The top layer of gear gets compressed and due to this a residual stress develops on the surface. Shot peening has additional advantage of increasing component hardness, removing micro cracks, cleaning surface etc. MMC material has been prepared by stir casting method as mentioned in previous section consisting of aluminium as matrix and silicon carbide as reinforcement. After processing on lathe machine for making the blanks, teeth are produced on gear shaping machine. This gear is having 48 numbers of teeth and 2 mm module and it is ready for shot peening. Shot peening is the method used to form residual compressive layers on the surface of gears. It is a cold working process to enhance mechanical properties of metal gears, MMCs gears.

Shot peening machines are of three types centrifugal machines, direct pressure machines and air jet machines. In the case of centrifugal machine the shots are allowed to rotate in the rotor and due to centrifugal force it gets bombarded on components. In direct pressure type shot peening machine working principal is to throw shots through nozzle. In the case of air jet machine the shots are allowed to move along with high jet of air through nozzles. Centrifugal type machine is used to produce dimples on gear surface by the application of centrifugal force. In this machine gear is loaded on the table and passes through the chamber. In this process steel shots of different shapes depending upon the characteristics requirement bombarded on the surface of metal components to create plastic deformation.

Shot material could be steel balls, steel wire piece, ceramic like alumina, glass balls etc. Different type of shot material to be used depends upon the component to be peened. Components that undergo repeated loading and unloading like gears, steel shots are preferred for high intensity peening i.e. impact of peening is at more depth of surface. For static components like brackets, housing of gear box, low and medium intensity peening is executed with glass or ceramic shots.

Steel balls of diameter 0.5 mm are used to produce residual compressive layer on the surface. The balls are having the hardness of about 58 to 60 HRC. Intensity is the term which is the measure of force with which the shot strikes the surface of the gear. For analyzing, almen test strip is used to measure the intensity of the shot, in this method a strip is bombarded with shots and the curvature obtained is measured on the almen gauge. Intensity of the shots depends upon distance from the nozzle, angle of nozzle and velocity.Balls are directed towards the rotating centrifugal wheel having diameter of 500 mm and rotating at a speed of 2000 rpm having flat blade to throw the steel balls. Gears are manually loaded and unloaded on conveyor while rest of the operation is automatic. Coverage reflects surface area of the gear exposed in the process of shot peening. Root fillet radius of the gear is to be strong enough, because it affects the bending strength of the tooth. Entire surface is covered to increase durability. Tooth profile i.e. involute surface of gear should be shot peened to impart pitting resistance and scoring. Lubrication during tooth mating is important. Small cavities which are generated after shot peening works like oil pocket. Gear tooth store lubricant between sliding surfaces. Coverage of the gear should be 100% as entire gear is to go under fatigue loading during its life span. To achieve this after one pass of gear it is reversed on the conveyor belt and again pass through the chamber to get both sides get shot peened. For measurement of the shot peening, specifications AMS2430 standards are used. Shot peening of intensity 4.3A is obtained on gear surface and average depth of 0.22 mm is developed as compressive residual layer. Surface roughness average of 3.2 μm is maintained on gear tooth surface.In GFRP gear there is requirement of coating to increase life of gear. For this purpose sand blasting is done to remove the un machined glass fibers reinforcement and matrix material from surface of gear. Sand blasting includes bombarding the surface with the sand particles which produce small indentations on the top layers. So that coating layers could become the integrated part of gear can fix firmly. Small pockets are used to store lubricating oils during operation.

3.11 SUMMARY

In this chapter, the development of setup for manufacturing GFRP and MMC has been discussed along with fabrication of gear blank on lathe machine within tolerance. The selection of machining parameters with their levels on gear shaper machine by pilot experiments has been done. Checking of quality parameters and the testing instruments has been explained. Optimization methods such as Taguchi, GRA, RSM with equation have been discussed. Experimental setup for composite material and noise measurement has been discussed. Details about the effect of shot peening and sand blasting of the gear with different parameters is presented in this chapter.

CHAPTER 4

MODELING OF GLASS FIBER REINFORCED POLYMER GEAR USING TAGUCHI AND GREY RELATIONAL ANALYSIS

4.1 INTRODUCTION

GFRP composite gear is used in a number of applications where fine motion transmission and silent rotation is required. In order to increase its usage there is a need to increase the quality of gear. Shrinkage problem is associated with injection molded gear. In present work, blank is prepared by injection molding and teeth are cut on gear shaper Therefore its metrology can be controlled by optimizing the machining parameters.

The composite gears are synthesized by different techniques but mostly injection molding technique is used. First is the classical technique in which the gear blank is manufactured on lathe machine then mounted on mandrel of indexing attachment of horizontal milling machine, the involute cutter of same module is used to cut single teeth one by one up to the full depth of teeth, second is to mount the gear blank on mandrel of gear shaper, gear blank is rotated and reciprocated in horizontal plane, cutter is rotated and reciprocated in vertical plane, third is to mount the gear blank in hobbing machine, cutter is rotated in horizontal plane and gear blank is rotated in vertical plane, fourth is mould prepared on vertical machine center having shape of final gear, mounted on injection molding machine, molten composite material is injected and final gear is obtained.

Gear forming process affects the performance of gears. Generally polymer gears are manufactured by injection molding machine shrinkage accuracy problem is associated with gears. In our case semi finished gears in the form of blanks obtained from injection molding machine and after that final gear is manufactured on gear shaper machine in order to control the root diameter deviation, tooth thickness variation and surface roughness through optimum process parameter selection.

In this chapter, gear shaper machine that uses GFRP material instead of conventional steel has been experimentally analyzed. The chapter presents the effect of process parameters on root diameter deviation (RD), tooth thickness variation (TT) and surface roughness (R_a) during shaping. The experimentation has been performed to determine effect of rotary feed, cutting speed, cutting fluid ratio and cutting fluid flow rate on RD, TT and R_a. It has been found that RD, TT and Ra improved significantly by optimizing the process parameters of gear shaper through Taguchi and Grey relational analysis.

ANOVA and the response table values are calculated from MINITAB 16 for determining the significant factors, their desirability and the confidence. A response table gives the optimal combination of different process parameters.

4.2 DETAILS OF WORK MATERIAL AND TOOL MATERIAL

GFRP could be fabricated by two methods. First one is glass fiber are laminated with polymer and second one is granules of polymers mixed with glass fibers could be taken. In present case second method is selected in which GFRP in the form of granules is taken. These granules are dried and put in the hopper of injection molding machine, heated and melted in semi solid form then injected into the mold cavity.

Table 4 .1:- Composition and properties of GFRP (DuPont Zytel 70G33LNC010)

S. No.	**Particular**	**Value**
1	Glass fiber	33 %
2	Resin-polyamide	66 %
3	Tensile modulus	10500 MPa
4	Poissions ratio	0.39
5	Notched charpy impact strength	13 kJ/m^2
6	Un notched charpy impact strength	85 kJ/m^2
7	Density	1390 Kg/m^3
8	Stress at break	200 MPa

In present case blank having diameter of 102 mm x 22 mm is prepared taking shrinkage into consideration.Engineering polymer of DuPont make Zytel 70G33LN010 with 33% glass fiber reinforced polyamide 66 resin has been chosen for making gear blanks detail of its properties are given in Table 4.1. The cutter used is of 50 teeth, 2 module and is of material high speed steel having 18% tungsten, 4% chromium, 1% vanadium as alloying element.

4.3 SELECTION OF PROCESS PARAMETERS

Table 4.2 shows four parameters and three levels. The range of process parameters are selected based on pilot experiments. Machine is run at cutting speed and rotary feed range available in gear shaper machine, trial runs are performed, upper range of these parameters are decided based on vibration and noise level originating while machining glass fiber reinforced gear with high speed steel cutter. Lower range is decided based on poor surface finish and pull out of glass fiber from the matrix. Table 4.3 show experimental results for root diameter deviation, tooth thickness variation and surface roughness.

In the case of gear shaper feeding of the uncut surface of gear blank take place through rotation of blank in horizontal plane and cutter reciprocates in vertical plane, so rotary feed depicts new uncut material in millimeter which come in contact with cutter in each stroke referred as mm/stroke.

In the fluid ratio, cutting fluid of servo system 68, Indian oil make is used and mixed with water in the percentage of 4, 8 and 12.

Table 4.2:- Process parameters of gear shaper.

Process parameters	Parameter Designation	Levels		
		L1	L2	L3
Rotary feed (mm/stroke)	F	0.15	0.17	0.19
Cutting speed (stroke/min)	S	180	210	240
Fluid ratio (percentage)	R	4	8	12
Fluid flow rate (ml/min)	FR	25	30	35

4.4 PLANNING OF EXPERIMENTS

Taguchi method is a technique to design quality systems based on orthogonal array which gives less variance for the experiments with optimum setting of parameters[55]. It is the combination of design of experiments with optimization of process for required results. It focuses on the effect of variation on the performance characteristics of process. Taguchi suggests that proper design of parameters should be done at offline phase. Taguchi works on the following steps; find out the objectives, find out the performance characteristics with measurement tools, find out the factors affecting performance characteristics with their levels and interactions if any, chose the orthogonal array and give the factors at their levels, perform the tests, analysis of the experimental data by signal to noise ratio, factor effects and the analysis of variance to locate the significant factors with their optimum levels, verification of the optimal design parameters by confirmation experiment. The S/N ratio is the ratio of mean to the standard deviation. The three subdivisions are Lower the better, higher the better, nominal the better. Analysis of variance is used to find out which parameter is having the significant effect. With the help of grey relational grade and ANOVA analysis the optimal combination can be find out. After that confirmation experiment is performed to verify the optimal parameter of the process.

4.5 EXPERIMENTAL DESIGN

Based on Taguchi orthogonal array 27 experiments were conducted by different machining parameters setting and 3 different levels and the results are given in Table 4.3.

Table 4.3:- Experimental result for L27 array

Run No.	Root diameter deviation (mm)	Tooth thickness variation (mm)	Surface roughness average (µm)
1	0.149	0.088	1.81
2	0.146	0.063	1.65
3	0.138	0.042	1.54
4	0.216	0.022	1.32
5	0.232	0.038	1.41

6	0.189	0.051	1.3
7	0.268	0.012	1.25
8	0.235	0.024	1.28
9	0.272	0.015	1.2
10	0.312	0.121	2.1
11	0.289	0.115	1.9
12	0.31	0.134	1.88
13	0.286	0.093	1.67
14	0.301	0.084	1.62
15	0.293	0.135	1.59
16	0.324	0.083	1.33
17	0.382	0.075	1.32
18	0.311	0.068	1.48
19	0.401	0.059	2.1
20	0.394	0.067	2.3
21	0.416	0.088	2.4
22	0.324	0.152	1.98
23	0.289	0.161	1.8
24	0.294	0.148	2.13
25	0.368	0.122	2.43
26	0.329	0.113	2.36
27	0.311	0.187	2.22

In the experiment number 10,11,12 as the rotary feed rate increases, cutting speed decreases, fluid ratio decreases the glass fibers remains uncut as the overlapping of cutting edge on work piece reduces due to which root diameter deviation, tooth thickness variation and surface roughness average increases.

4.6 GREY RELATIONAL ANALYSIS BASED TAGUCHI DESIGN

The orthogonal array is a full or fractional factorial matrix that gives adequate comparison of levels of the process. In the present analysis an L27 orthogonal array is used. Grey relational analysis is a technique that can be used for decision making of multiple attribute [69]. In GRA the experimental results of root diameter deviation, tooth thickness variation and surface roughness are normalized in the range between zeros to one. The data for root diameter deviation, tooth thickness variation, surface roughness is minimized and expressed as:

$$x'_i(j) = \frac{max_j y_{ij} - y_{ij}}{max_j y_{ij} - min_j y_{ij}} \quad (4.1)$$

Then a normalized matrix is obtained by equation 4.1. From the normalized matrix a reference value is generated using equation 4.2, as the largest value of normalized value for each entity.

$$x'_0(j) = max^n_{i=1} x'_i(j) \quad (4.2)$$

The next step is to make the difference matrix by subtracting normalized entity from reference value through equation 4.3.

$$\Delta_{oi}(j) = | x'_0(j) - x'_i(j) | \quad (4.3)$$

Then, the grey relational coefficients are find out using equation (4.4).It shows the relationship between the desired and actual experimental values

$$\delta_{oi}(j) = \frac{min^n_{i=1} min^m_{j=1} \Delta_{oi}(j) + \zeta \times max^n_{i=1} max^m_{j=1} \Delta_{oi}(j)}{\Delta_{oi}(j) + \zeta \times max^n_{i=1} max^m_{j=1} \Delta_{oi}(j)} \quad (4.4)$$

Where ζ ($0 \leq \zeta \leq 1$) is known as the distinguishing coefficient .If the value of ζ is small there will be more distinguish ability. In most cases,ζ takes the value of 0.5 because this value usually gives slight distinguishing effects and good balance [118].

4.7 GREY RELATIONAL ANALYSIS BASED TAGUCHI OPTIMIZATION

After this a weighting method is used to find out the grey relational grade for every experiment. This grey relational grade is the value which shows the optimization of multiple performance characteristics.

$$\gamma_{oi} = \frac{1}{m} \sum_{i=1}^{m} \delta_{oi}(j) \quad (4.5)$$

The grey relational grade is obtained through equation (4.5) while considering the same weight age for performance characteristics i.e. 1. In equation (4.5), m is the number of performance characteristics.

Table 4.4:- Normalized matrix

Run No.	Root diameter deviation	Tooth thickness variation	Surface roughness
1	0.9604	0.5657	0.5041
2	0.9712	0.7086	0.6341
3	1.0000	0.8286	0.7236
4	0.7194	0.9429	0.9024
5	0.6619	0.8514	0.8293
6	0.8165	0.7771	0.9187
7	0.5324	1.0000	0.9593
8	0.6511	0.9314	0.9350
9	0.5180	0.9829	1.0000
10	0.3741	0.3771	0.2683
11	0.4568	0.4114	0.4309
12	0.3813	0.3029	0.4472
13	0.4676	0.5371	0.6179
14	0.4137	0.5886	0.6585
15	0.4424	0.2971	0.6829
16	0.3309	0.5943	0.8943
17	0.1223	0.6400	0.9024
18	0.3777	0.6800	0.7724
19	0.0540	0.7314	0.2683
20	0.0791	0.6857	0.1057
21	0.0000	0.5657	0.0244
22	0.3309	0.2000	0.3659
23	0.4568	0.1486	0.5122
24	0.4388	0.2229	0.2439
25	0.1727	0.3714	0.0000
26	0.3129	0.4229	0.0569
27	0.3777	0.0000	0.1707

Table 4.5:- Grey relational coefficient

Run No.	Root diameter deviation	Tooth thickness variation	Surface roughness
1	0.9267	0.5352	0.5020
2	0.9456	0.6318	0.5775
3	1.0000	0.7447	0.6440
4	0.6406	0.8974	0.8367
5	0.5966	0.7709	0.7455
6	0.7316	0.6917	0.8601
7	0.5167	1.0000	0.9248
8	0.5890	0.8794	0.8849
9	0.5092	0.9669	1.0000
10	0.4441	0.4453	0.4059
11	0.4793	0.4593	0.4677
12	0.4469	0.4177	0.4749
13	0.4843	0.5193	0.5668
14	0.4603	0.5486	0.5942
15	0.4728	0.4157	0.6119
16	0.4277	0.5521	0.8255
17	0.3629	0.5814	0.8367
18	0.4455	0.6098	0.6872
19	0.3458	0.6506	0.4059
20	0.3519	0.6140	0.3586
21	0.3333	0.5352	0.3388
22	0.4277	0.3846	0.4409
23	0.4793	0.3700	0.5062
24	0.4712	0.3915	0.3981
25	0.3767	0.4430	0.3333
26	0.4212	0.4642	0.3465
27	0.4455	0.3333	0.3761

Table 4.6:- Grey relational grade for performance characteristics.

Run. No.	Grey relational grade
1	0.6546
2	0.7183
3	0.7962
4	0.7916
5	0.7043
6	0.7611
7	0.8138
8	0.7844
9	0.8253
10	0.4318
11	0.4688
12	0.4465
13	0.5235
14	0.5344
15	0.5001
16	0.6017
17	0.5937
18	0.5808
19	0.4674
20	0.4415
21	0.4024
22	0.4177
23	0.4518
24	0.4202
25	0.3844
26	0.4106
27	0.3850

After this ANOVA and Taguchi analysis are performed on grey relational grade with statistical software MINITAB 16 to determine the important process parameter. It is useful for obtaining the best combination of process parameters for optimal performance characteristics.

4.8 RESPONSE TABLE AND ANOVA

ANOVA and the response table values are calculated from MINITAB 16 for determining the significant factors, their desirability and the confidence. A response Table 4.7 is made for different process parameters. Rotary feed has the greatest impact on the performance characteristics having grey relational grade value of 0.7611 at level 1, cutting speed is at rank 2 with highest grade value 0.5978 at level 3, cutting fluid ratio at rank 3 with grade value 0.5881 at level 3, Fluid flow rate is at last rank with grade value of 0.5939 at level 2.

Table 4.7:- Response for grey relational grade.

Level	**F**	**S**	**R**	**FR**
1	0.7611	0.5364	0.5817	0.5452
2	0.5201	0.5672	0.5316	0.5939
3	0.4201	0.5978	0.5881	0.5623
Delta	0.341	0.0614	0.0565	0.0486
Rank	1	2	3	4

Table 4.8:- ANOVA for grey relational grade.

Source	**df**	**SS**	**MS**	**F**	**p-value**	**p-value, order**
F	2	0.552921	0.276461	252.46	0.000	1
S	2	0.016945	0.008473	7.74	0.004	3
R	2	0.017252	0.008626	7.88	0.003	2
FR	2	0.010955	0.005478	5	0.019	4
Error	18	0.019711	0.001095			
Total	26	0.617785				
	S=0.0330919	R-Sq=96.81%	R-Sq(adj)=95.39%			

The cutting fluid flow rate has the least impact. It is also known that for a process parameter whose p-value is below 0.05 has a significant effect on the performance characteristics, and p-value between 0.05 and 0.1 shows the low significant effect [118]. The parameter has the lowest effect on the process whose p-value is more than 0.1. From the ANOVA Table 4.8, Rotary feed is the most significant factor with the p-value 0, Fluid ratio is at number 2 with p-value 0.003, cutting speed is at number 3 with p-value 0.004 and the fluid flow rate is at last with p-value 0.019. Hence, it is found that all the process parameters have significant effect on the performance characteristics of GFRP gear.

4.9 MAIN EFFECT PLOT FOR MEANS

As shown in Figure 4.1, the relationship of process parameters with grey relational grade is described. For Rotary feed with the increase of value from 0.15 mm/stroke at level 1, 0.17 mm/stroke to 0.19 mm/stroke,

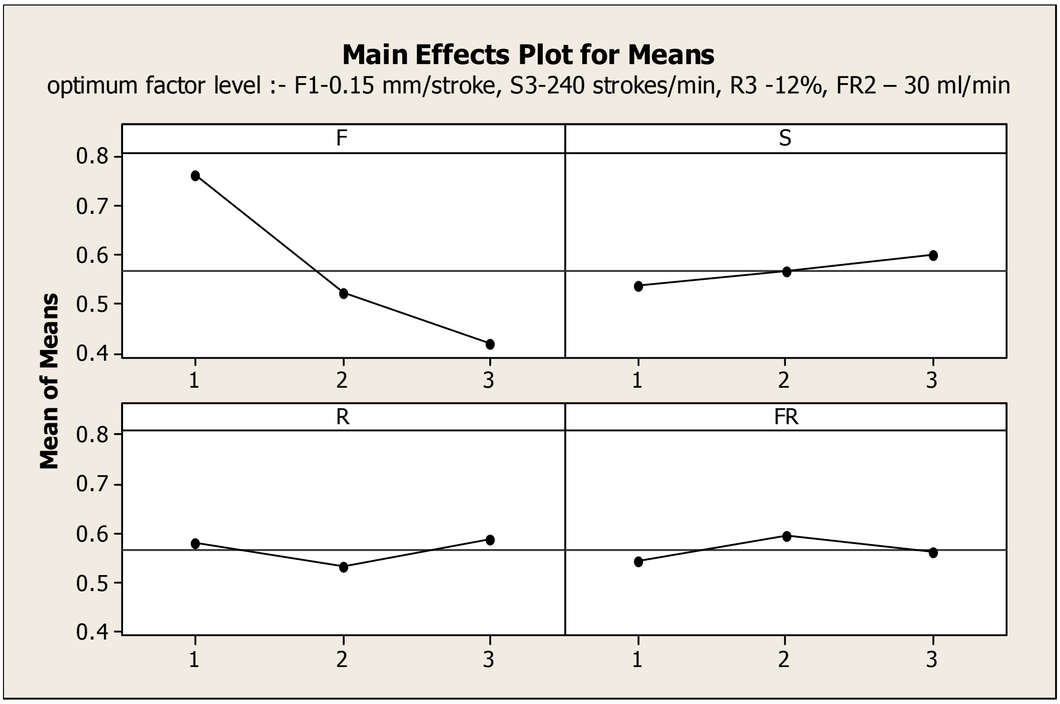

Figure 4.1:- Main effect plot for means.

line in the graph is having high slope which means rotary feed is affecting the root diameter deviation, tooth thickness variation and surface roughness to great extent. As the rotary feed is increasing grade value is decreasing and for good performance higher grade value is required. At low rotary feed the number of strokes per teeth cutting increases and overlapping of material removal take place on each pass of cutter so surface roughness, root diameter deviation, tooth thickness variation values is low.

In the graph of cutting speed levels and grey relational grade the slope is low, as the cutting speed increases from 180 strokes/min, 210 strokes/min and 240 strokes/min. The grade values starts on increasing because at high speed due to impact, the glass fibers cut at once and get detached from nylon66 matrix and over lapping of cutter on each pass ensures reduction in surface roughness, root diameter deviation and tooth thickness variation.

In the graph of cutting fluid ratio, as the ratio increased from 4 to 8 the grade value reduces i.e. root diameter deviation, tooth thickness variation and surface roughness increase due to moisture absorption nature of polymer, the glass fiber reinforcement not get cut due this. As the ratio is further increased from 8 to 12 moisture absorption rate GFRP decrease due to high value of cutting oil in water, at this GFRP material gets cut and detached from gear tooth in the form of chip.

In the graph of cutting fluid flow rate the value increase 25 ml/min to 35 ml/min. At the start grade value increases due to fast removal of chips and fine glass fiber from the work piece cutter interface but at high flow rate the fine glass fiber start coming in contact with cutter work piece interface because of high turbulence and surface roughness, root diameter deviation, tooth thickness variation increases.

4.10 METHODLOGY

GRA and Taguchi analysis is a technique, in which multiple performance characteristics is converted into single grey relational grade and responses are judged, validated with ANOVA as shown in Figure 4.1. Hence, the present study considers optimization of root diameter deviation, tooth thickness variation and surface roughness using Taguchi orthogonal design with four process parameters viz. rotary feed, cutting speed, cutting fluid ratio, cutting fluid flow rate. A gear shaper machine is a machine in which gear blanks are mounted on mandrel at vertical axis having rotary and reciprocating motion. Cutter is having shape of gear have reciprocating motion in vertical plane with rotary motion so that all the cutting edges of the cutter are utilized. The test results are analyzed for optimal combination of process parameter as predicted by Taguchi and grey relational method. After that Analysis of variance (ANOVA) is carried out to analyze the effect of process parameters and their interactions on the performance characteristics of the gears

4.11 EXPERIMENTAL RESULT AND OPTIMIZATION

As shown in Figure 4.2, the root diameter deviation is highest in experiment number 21 which is 0.416 having rotary feed of 0.19 mm/stroke, cutting speed 180 stroke/min, fluid ratio 12, fluid flow rate 30 ml/min. The root diameter deviation is lowest in experiment number 3 which is 0.138 having rotary feed 0.15 mm/stroke, cutting speed 180 stroke/min, cutting fluid ratio 4, cutting fluid flow rate 25 ml/min.As shown in Figure 4.3 , the tooth to tooth variation is highest in experiment number 27 which is 0.187 having rotary feed of 0.19 mm/stroke, cutting speed 240 stroke/min, fluid ratio 8, fluid flow rate 25 ml/min.

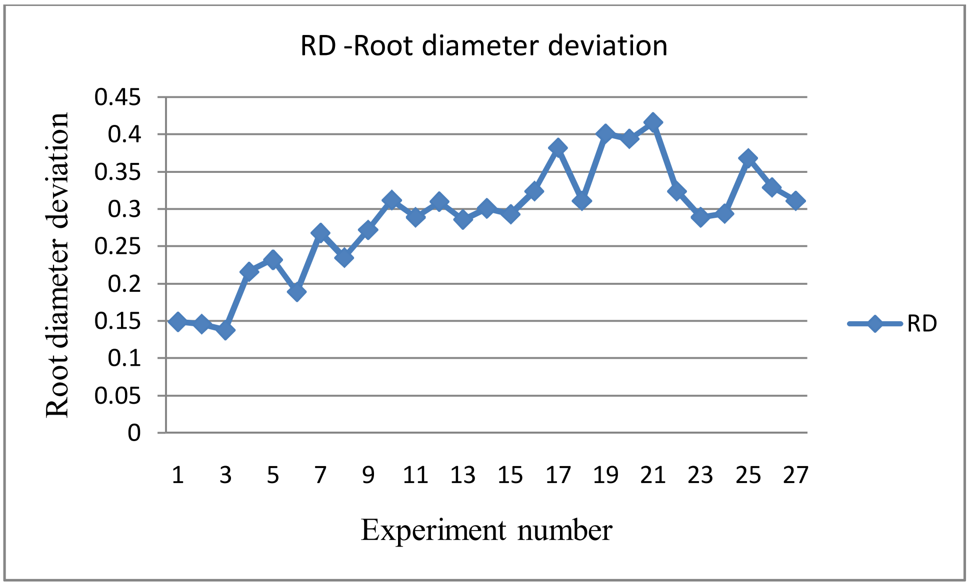

Figure 4.2 Trend analysis of root diameter deviation with L27 array.

The tooth to tooth variation is lowest in experiment number 7 which is 0.021 having rotary feed 0.15 mm/stroke, cutting speed 240 stroke/min, cutting fluid ratio 12, cutting fluid flow rate 35 ml/min.

As shown in Figure 4.4 , the roughness average is highest in experiment number 25 which is 2.43 having rotary feed of 0.19 mm/stroke, cutting speed 240 stroke/min, fluid ratio 8, fluid flow rate 25 ml/min. The roughness is lowest in experiment number

9 which is 1.2 having rotary feed 0.15mm/stroke, cutting speed 240 stroke/min, cutting fluid ratio 12, cutting fluid flow rate 35 ml/min.

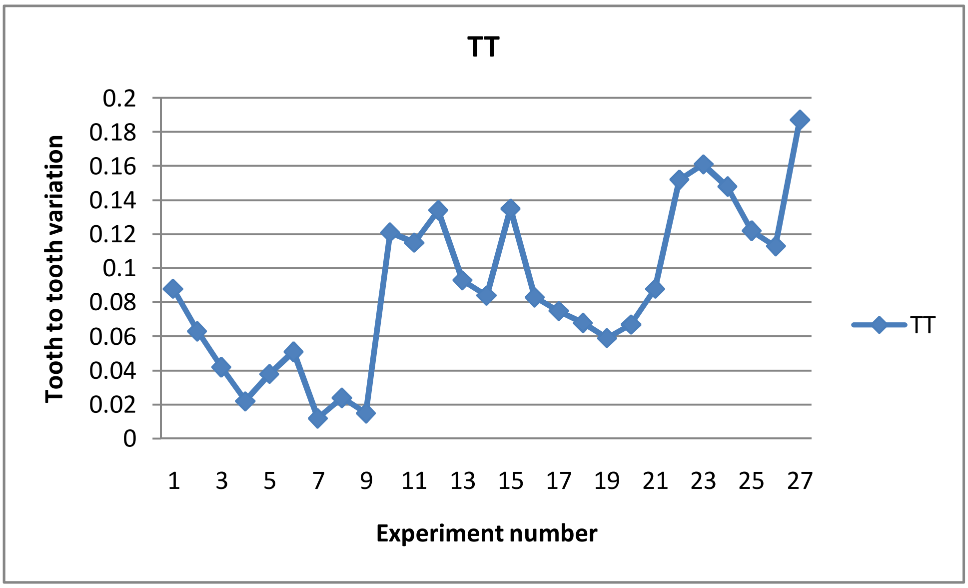

Figure 4.3 Trend analysis of tooth to tooth variation with L27 array.

As shown in Figure 4.4 , the roughness average is highest in experiment number 25 which is 2.43 having rotary feed of 0.19 mm/stroke, cutting speed 240 stroke/min, fluid ratio 8, fluid flow rate 25 ml/min. The roughness is lowest in experiment number 9 which is 1.2 having rotary feed 0.15mm/stroke, cutting speed 240 stroke/min, cutting fluid ratio 12, cutting fluid flow rate 35 ml/min.

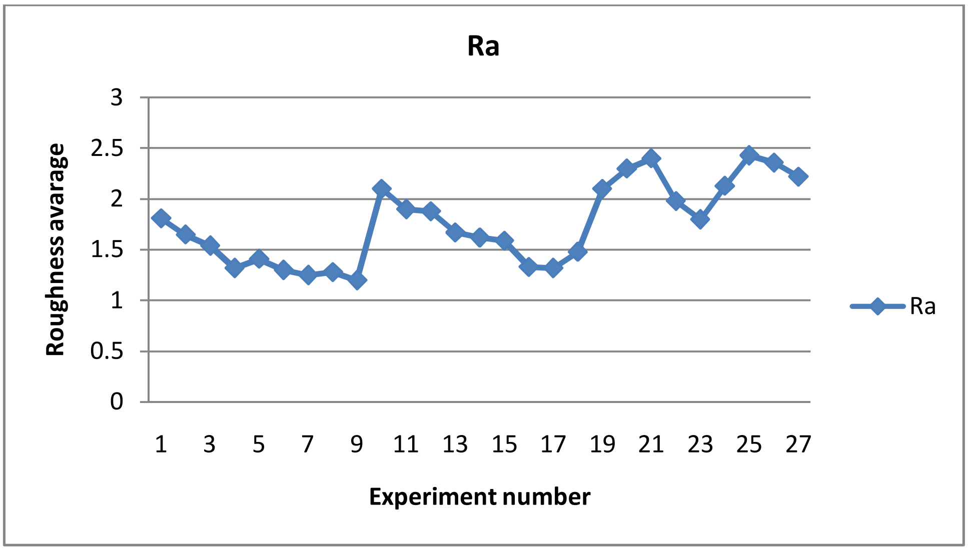

Figure 4.4 Trend analysis of Roughness average with L27 array.

4.12 DISCUSSION

A normalized matrix is made for minimum root diameter deviation, tooth thickness variation and surface roughness by equation (4.1).The elements of the normalized matrix along with reference sequence element are shown in Table 4.4.

After that, the grey relational coefficients were obtained by using equation (4.4). It expresses the relationship between the best (reference value) and actual normalized value. The grey relational coefficients are represented in Table 4.5.

Using equation (5) the grey relational grade of comparability sequence for j=1-27 was find out and shown in Table 4.6. The same weighted values assigned to the performance characteristics by assuming that they are equally significant. So for optimization the multiple performance characteristics has to be converted into a single grey relational grade, which represents overall weight age of process parameters for optimal performance characteristics.

Senthilvelon et al [90] found out that glass fiber reinforced nylon gear has involute profile deviation of 42.2 micron, involute profile form deviation of 20.6 micron, lead deviation of 52 microns, radial run out of 281 microns due to shrinkage problem of gear in injection molding problem which is uncontrolled whereas in present case by optimizing the machining parameters the gear root diameter deviation minimized from 0.312 mm to 0.213 mm, tooth thickness variation is minimized from 0.187 mm to 0.165 mm and surface roughness is minimized from 2.43 micron to 1 micron.

4.13 CONFIRMATION TEST

The best group of process parameters for optimum performance is determined from response Table by Taguchi analysis as given in Table 4.7, and their levels are F1S3R3FR2.Further the investigation is confirmed by ANOVA, as shown in Table 4.8. The optimal grey relational grade γ_{opt} is obtained by following equation:

$$\gamma_{opt} = \gamma_m \sum_{i=1}^{n} (\gamma_i - \gamma_m) \quad (4.6)$$

Where γ_m is the average of grey relational grade, γ_i is the average of grey relational grade at optimum level and n is the number of affecting process parameters. Rotary feed, Cutting speed, cutting fluid ratio, cutting fluid flow rate are all the significant parameters used for predicting the optimal grey relational grade. The predicted value of optimal grey relational grade is expressed as:

$$\gamma_{opt} = \gamma_m + \sum_{i=1}^{4}(\gamma_i - \gamma_m)$$

= 0.5671 + (0.7611-0.5671) + (0.5978-0.5671) + (0.5881-0.5671) + (0.5939-0.5671) = 0.8459

Table 4.9:- Experimental and Predicted values of grey relational grade.

Performance characteristics	**Pred. value**	**Av. value**	**Exp. 1**	**Exp. 2**	**Exp. 3**
Optimal parameters	F1S3R3 FR2	F1S3R3 FR2	F1S3R3 FR2	F1S3R3 FR2	F1S3R3FR2
Root diameter deviation (mm)		0.213	0.224	0.208	0.207
Tooth thickness variation (mm)		0.165	0.142	0.183	0.170
Surface roughness (µm)		1.00	1.13	0.98	0.89
Grey relational grade	0.8459	0.8318			

Three experiments are performed taking best process parameters for optimum quality characteristics and the results are depicted in Table 4.9. By this technique, cutting parameters of gear shaper is successfully optimized for root diameter deviation, tooth thickness variation and surface roughness.

In the present work, as manufacturing of polymer gears are generally executed through injection molding process in single step but in the present study the gears are machined on gear shaper. In the literature only improvement rate for surface roughness could be compared [58] and improvement in surface roughness is 49.8 %.

4.14 SUMMARY

In the present chapter, the cutting parameters of gear shaper machine have been found out to optimize the quality response of gear tolerances by GRA and Taguchi analysis. It has been found that best quality characteristics for optimum process parameters were found using GRA : RD 0.213 mm for the range of 0.138 to 0.416 mm, TT 0.165 mm for the range of 0.012 to 0.187 mm and R_a 1 µm for the range of 1.2 to 2.43 µm obtained. Surface roughness improvement in this work is 49.8 % higher as compared to result available in literature. For the gear shaper, the cutting parameters for optimum quality response are rotary feed 0.15 mm/stroke, cutting speed 240 strokes/min, cutting fluid ratio 12% and cutting fluid flow rate 30 ml/min and these significant parameters effect the performance characteristics are at 96% confidence level. It has been validated that variation in predicted and experimental grey relational grade is very less (1.5 %).It has been proved that by gear shaping the tolerances could be controlled in comparison to injection molding process where shrinkage problem is there. Rotary feed, cutting speed, cutting fluid ratio and cutting fluid flow rate are identified as key significant parameters of gear shaper machine which control the performance characteristics as p value in the ANOVA is less than 0.02.

CHAPTER 5

PERFORMANCE ANALYSIS AND MODELLING OF GLASS FIBER REINFORCED POLYMER GEAR USING RESPONSE SURFACE METHODOLOGY

5.1 INTRODUCTION

Polymer composite material is the emerging materials in mechanical power transmission applications. GFRP gears are preferred for light weight applications in many areas like automotive, space and aviation industries, due to its high mechanical properties, excellent wear, noise less operation, corrosion resistant, neat and clean environment (no need of lubrication) during power transmission. At present, great interest is to investigate for effective means for machining of polymer composite materials to achieve low surface roughness. Surface roughness is one of the governing factors in controlling the life, noise, vibration of gears during power transmission. In the spur gear the addendum region and dedendum region above and below the pitch circle diameter is the region where sliding of the tooth surfaces takes place. In order to sustain the involute profile. Surface finish should be high enough which increase life of gear tooth. In this chapter surface roughness is taken as single response parameter to be optimized with cutting parameters of gear shaper including cutting speed, rotary feed and cutting fluid ratio. In this work, the GFRP gears were manufactured in three steps: blanks were produced by injection molding process, machined on lathe machine and teeth are cut on gear shaper. Cutting speed, rotary feed and cutting fluid ratio were the cutting parameters selected for the optimization of surface roughness of gear teeth through response surface methodology. Three confirmation tests were done to validate the optimal combination of process parameters as predicted by RSM. Injection molded spur gear is associated with the problem of shrinkage and surface roughness due to presence of hard glass fibers. Surface roughness is the important parameter that needs to be controlled. Gear is the dynamic machine element, during working surface roughness play important role in controlling the vibrations. Contact area should be more for proper mating. In the case of gears surface roughness of teeth is the important output response characteristics because teeth of gear come in contact again and again. Due to this vibration, wear, load carrying capacity, noise and life of gear get influenced.

5.2 MATERIAL

In this study engineering polymer Zytel 70G33LN010 having 33% glass fiber manufactured by DuPont in the form of granules has been chosen for making the gears. In this base matrix is polyamide 66 and the reinforcement is glass fibers. Properties of the material are given in Table 5.1.

Table 5.1 GFRP gear material

S.No.	Particular	Value
1	Density	1390 Kg/m^3
2	Stress at break	200 MPa
3	Tensile modulus	10500 MPa
4	Poisson's ratio	0.39

5.3 METHODS

First of all gear specifications are finalized as number of teeth 48, module 2 mm, pressure angle $20^0$and face width 10 mm. Based on gear specifications the gear blanks are prepared on injection molding machines. These rough blanks are machined on turning machines to make the final size. When final size is completed the finished gear blanks are sent to gear shaper machine to obtain the desired number of teeth within tolerances. To predict the surface roughness surface response methodology is adopted to obtain the model of second order. By doing the pilot experiments the cutting parameters are selected, followed by design of experiments. By finalizing the desired number of experiments the surface roughness data is obtained with the help of surface roughness tester.

5.4 GEAR SPECIFICATION

Engineering polymer Zytel 70G33LN010 having 33% glass fibre manufactured by DuPont in the form of granules is dried at 353 K for 4 hours, this material is put into injection molding machine in the mould and solid blanks are obtained.The solid blanks obtained from injection molding is mounted on three jaw chuck of kirloskar make lathe machine, firstly one side of the blank is operated with facing, drilling followed by boring and turning. After that side is reversed then operations of turning and facing were performed. The finished gear blank is mounted on the vertical mandrel of HMT make gear shaper model S150 to cut the teeth .It is properly mounted on the gear shaper spindle. The cutter is having reciprocating motion along with rotation on its axis so that all the cutting edges are used.

Table 5.2 Specification of GFRP Gear

S.No.	Description	Symbol	Formula	value
1	Number of teeth (Nos)	z	z=d/m	48
2	Module (mm)	m	m=d/z	2
3	Addendum (mm)	ha	ha=1m	2
4	Dedendum (mm)	hf	hf=1.25m	2.5
5	Pressure angle	α	Degree	20

5.5 RESPONSE SURFACE METHODOLOGY

Response surface methodology (RSM) is used to reduce the large number of experimental investigations. In this a theoretical model is obtained which gives the results which are near to experimental values. The investigations fit into the theoretical model which is accurate enough to go with the results. In present case variables are rotary feed (y1), cutting speed (y2), fluid ratio (y3) and result is surface roughness (x). The samples are manufactured by changing the process parameters as per design of experiments and the response surface methodology has been used to plan and analyze surface roughness. Box-Behnken design is used to investigate quadratic effect of factors after finding out the important factors using screening factorial experiments.

Response surface methodology is statistical and mathematical technique. It is used for the modeling and analysis of problems in which interested response (surface roughness) is influenced by the variables (cutting parameters) and the target is to obtain the minimum surface roughness by selecting the optimum parameters.

The second order response surface model is obtained with the help of DOE and Minitab. Equation is checked for validity by inserting the variable. The results are compared with experimental values which are within limits. The analysis of variance shows that experimental data fits well into the calculated second order RSM model. From the results it is evident that response surface methodology is an important technique in statistics which is used to explain influence of rotary feed, cutting speed, fluid ratio on surface roughness.

The graph between the predicted and experimental values is nearer to straight line and validates fitness of the model. Effect of significant parameters on performance characteristics are near to 100% confidence level. Thus Second order model has been developed to predict the surface roughness using response surface methodology based on cutting parameters.

5.6 DESIGN FACTORS WITH LEVELS

The range of process parameters are selected based on pilot experiments. Table 5.3 shows three parameters and three levels. For gear shaper rotation of the uncut surface of work piece is through rotation of blank in vertical axis and cutter reciprocates in vertical plane, so rotary feed corresponds to new material in millimeter which comes in contact with cutter per stroke referred as mm/stroke.

Table 5.3 Process parameters and their levels.

Parameters	**symbol**	**Levels**		
		L1	**L2**	**L3**
Rotary feed (mm/stroke)	F	0.15	0.17	0.19
Cutting speed (stroke/min)	S	180	210	240
Fluid ratio (percentage)	R	4	8	12

5.7 DESIGN OF EXPERIMENTS

The Box-Behnken design is used to study the quadratic effect of factors after identifying the significant factors using screening factorial experiments. Array of experiments is given in Table 5.4.

5.8 SURFACE ROUGHNESS TEST

The average surface roughness is measured by using the Mitutoyo make Surftest SJ-301 instrument. Data is given in Table 5.4. As the stylus of tester is the precision part, it is gently put on the teeth surface of the gear and allowed to move in the perpendicular direction of the machined surface to measure the accurate values. The experiments are executed as per the design matrix and the surface roughness readings are shown in the table as per the experiments.

5.9 RESULT AND DISCUSSION

The data obtained from the surface roughness test for 17 experiments are used for optimization of the output response by selecting the cutting parameters by using RSM technique.

Table 5.4 Data of surface roughness of gear teeth

S.No.	F	S	R	R_a
1	0.15	180	8	1.425
2	0.19	180	8	1.059
3	0.15	240	8	2.076
4	0.19	240	8	1.913
5	0.15	210	4	2.373
6	0.15	180	8	1.42
7	0.15	210	12	2.2
8	0.19	210	12	1.34
9	0.17	180	4	1.514
10	0.17	180	12	1.56
11	0.17	180	12	1.522
12	0.17	240	12	1.265
13	0.17	210	8	1.213
14	0.17	210	8	1.362
15	0.17	210	8	1.278
16	0.17	210	8	1.118
17	0.17	210	8	1.203

The data is first uploaded in MINITAB 16 software and response surface analysis is performed.In the experimentation cutting speed varied from 180 strokes/min to 240 strokes/min. Value of rotary feed varied from 0.15 mm/stroke to 0.19 mm/stroke. Cutting fluid ratio varied from 4 % to 12 %.

5.10 ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance technique is useful for checking adequacy of the calculated empirical relationship. The perfectness of the fit of the model is checked by determination coefficient R^2.As shown in Table 5.5, the coefficient of determination calculated is 97.61% for surface roughness. It states that 97.61% of the experimental data validate the compatibility for the predicted data in the model.

Table 5.5 Analysis of variance for surface roughness

Source	**DF**	**SS**	**MS**	**F**	**p**
Model	7	2.36	0.338	52.6	0.000
F	1	0.59	0.08	12.4	0.006
S	1	0.26	0.74	114	0.000
R	1	0.011	0.557	87	0.000
F^2	1	0.388	0.515	80	0.000
R^2	1	0.526	0.94	147	0.000
SR	1	0.517	0.517	80	0.000
FR	1	0.067	0.213	33	0.000
Resi.	9	0.057	0.001		
Lack of fit	3	0.02	0.007	1.41	0.328
Pure error	6	0.03	0.005		
Total	16	2.42			
S=0.08, R-Sq. (adj) = 95.76%, R-Sq.= 97.61%					
Press = 0.296					

Higher R-square values are desired for data to fit into the model, its value falls in between 0 and 100%.The value of R-Sq adjusted is 95.76 % which shows the high significance of model and its value increases if new term will be added. The p-value gives the significance of the parameter if p-value is more than 0.05 then the parameter is not significant and if p-value is less than 0.05 then the parameter is significant [118]. As shown in the ANOVA table the three parameters as per the significance in ascending order is rotary feed, cutting fluid ratio, cutting speed having the F value of 12.4, 87 and 114 respectively.

A value of process parameter whose p-value is below 0.05 has a significant effect on the performance characteristics, and p-value between 0.05 and 0.1 shows the low significant effect. The parameter has the lowest effect on the process whose p-value is more than 0.1.The final relationship was constructed using these coefficients; it includes constant terms, single terms, square terms and interaction terms. The parameters whose p-value is more than 0.05 is removed from the model and final empirical relationship obtained is given as equation (5.4).

Surface roughness = + 17.3682-284.208 rotary feed + 0.0424327 cutting speed + 0.826720 cutting fluid ratio + 917.931 rotary feed*rotary feed + 0.0371587 cutting fluid ratio*cutting fluid ratio – 4.21573 rotary feed*cutting fluid ratio – 0.00387183 cutting speed*cutting fluid ratio. (5.4)

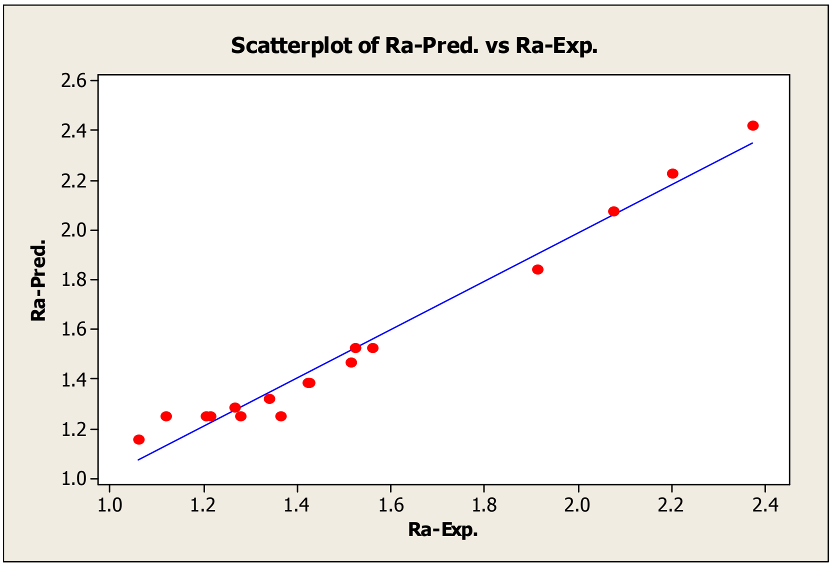

Figure 5.1 Scatter plot

The predicted values of the cutting parameters are obtained by inserting these values in equation (5.4) and residuals are obtained by subtracting from the experimental data. As shown in the Table 5.7 the residual values are very small which accounts for validity of this empirical relationship. Scatter plot between the surface roughness obtained by putting the values of cutting parameters in equation 5.4 and surface roughness obtained experimentally along with the residuals is shown in Figure 5.1.The data is scattered roughly along the straight line. Hence it is proved that the regression equation is following the experimental results.

Table 5.6 Residuals for surface roughness.

S.No.	R_a-Pred.	R_a-Exp.	Residual
1	1.386	1.425	0.0391
2	1.152	1.059	-0.0934
3	2.073	2.076	0.0026
4	1.840	1.913	0.0731
5	2.421	2.373	-0.0480
6	1.386	1.42	0.0341
7	2.227	2.2	-0.0275
8	1.319	1.34	0.0205
9	1.466	1.514	0.0481
10	1.527	1.56	0.0328
11	1.527	1.522	-0.0052
12	1.285	1.265	-0.0204
13	1.246	1.213	-0.0328
14	1.246	1.362	0.1162
15	1.246	1.278	0.0322
16	1.246	1.118	-0.1278
17	1.246	1.203	-0.0428

5.11 MAIN EFFECTS PLOT FOR SURFACE ROUGHNESS

Figure 5.2 shows main effects plot for surface roughness. Surface roughness is having minimum value for cutting speed of 180 stroke/min, rotary feed of 0.17 mm/stroke and cutting fluid ratio of 8%.At rotary feed of 0.17 mm/stroke glass fiber get properly cut at the surface of matrix material. At high cutting speed fiber pull out takes place and is optimum at 180 stroke/min.At fluid ratio of 12% due to presence of cutting oil matrix material get soft and glass fiber pull out takes place resulting in small pores on the surface there by increasing roughness. At fluid ratio of 4% glass fiber get cut above the surface of matrix resulting in poor surface finish.

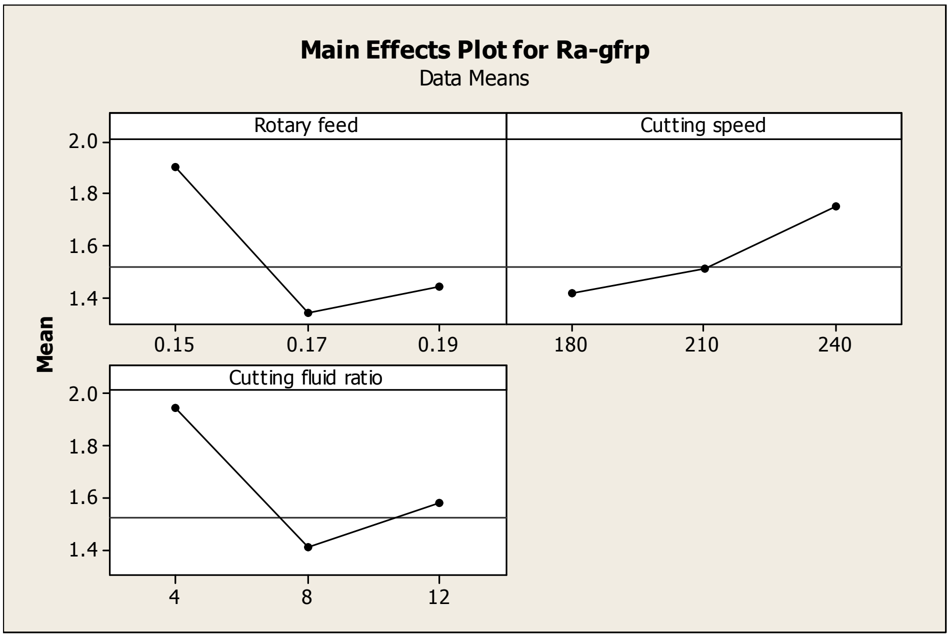

Figure 5.2 Main effects plot for surface roughness

5.12 SURFACE PLOT

After removing the insignificant parameters from the regression equation, it is left with two interactions. First is in between rotary feed and cutting fluid ratio, second is in between cutting speed and cutting fluid ratio. The surface plot is one of the most effective means of illustrating and interpreting the surface design. The surface contour plots of R_a drawn with the help of MATLAB 2013 software.

5.12.1 INTERACTION BETWEEN CUTTING FLUID RATIO AND ROTARY FEED

It can be deduced from response surface shown in Figure 5.2, that surface roughness is having a minimum value of 0.82 µm at cutting fluid ratio of 8% and rotary feed of 0.17 mm/stroke. It is due to the fact that as rotary feed comes at this value the glass fibers get wet properly at fluid ratio of 8% and get detached after cutting from the matrix material. At cutting fluid ratio of 12 and rotary feed 0.15 mm/stroke surface roughness is 1.9 µm.

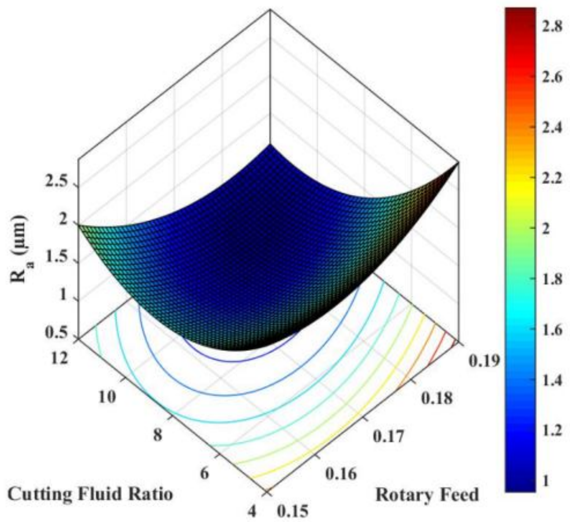

Figure 5.3 Surface plots between cutting fluid ratio and rotary feed

This increment is due to increase in pullout of glass fibers due to presence of high value of cutting fluid which weaken the matrix reinforcement bond. At rotary feed of 0.19 mm/stroke and cutting fluid ratio of 4 surface roughness value is 2.6. For these values hard glass fibers get cut above the surface of matrix and results in small projections which increases the surface roughness

5.12.2 INTERACTION BETWEEN CUTTING FLUID RATIO AND CUTTING SPEED

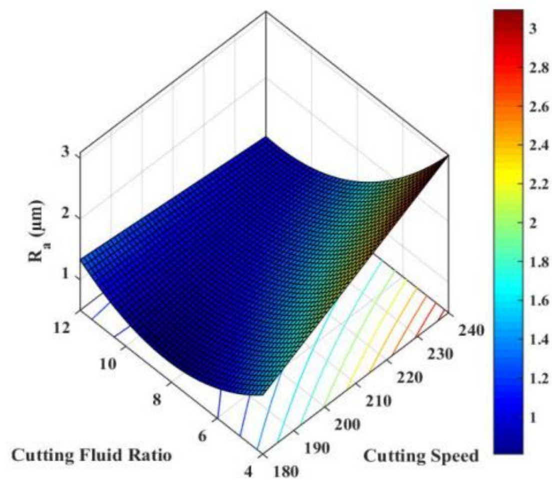

Figure 5.4 Surface plots between cutting fluid ratio and cutting speed

At this cutting speed the glass fibers and matrix get properly wet due to fluid ratio of 8% and removed from matrix material smoothly. For cutting speed of 180 strokes/min at cutting fluid ratio of 12 %, surface roughness is having the value of 1.3 µm, as due to increase of fluid ratio and cutting speed fiber pull out takes palce.

5.13 CONFIRMATION TEST

By taking the optimum cutting parameter into account from the surface plot, gear shaper machine set at cutting speed of 180 strokes/min, rotary feed of 0.17 mm/stroke, cutting fluid ratio of 8%; 3 experiments have been performed as shown in Table 5.8 and the average value of surface roughness obtained is 0.82 µm which is near to predicted value of 0.902 µm. By using response surface methodology, cutting parameters of gear shaper is successfully optimized for surface roughness of spur gear teeth. The detail of the experiments is given in Table 5.7, where D is the description, PL is parameter with level and R_a is surface roughness.

Table 5.7 Experimental Values

D	**Pred. value**	**Av. value**	**Exp. 1**	**Exp. 2**	**Exp. 3**
PL	S1F2R2	S1F2R2	S1F2R2	S1F2R2	S1F2R2
R_a	0.902	0.82	0.85	0.8	0.81

5.14 SUMMARY

In this chapter selection of the three parameters of gear shaper has been done at which surface roughness of gear blank is optimized with the use of response surface methodology. Box Behnken design 17 experiments have been performed to obtain output responses. The best predicted surface roughness found is 0.902 µm which is closed to experimental value of 0.82 µm. The optimum machining parameters has been found as cutting fluid ratio 8%, cutting speed 180 strokes/min., Rotary feed 0.17 mm/stroke. The significant parameters affect the performance characteristics are at 97.61 % confidence level.The second order model has been developed to predict the surface roughness using response surface methodology based on cutting parameters. It is having R-square adjusted value of 95.76% which shows the correctness of the model if new terms will be added.

CHAPTER 6

COMPUTER AIDED ENGINEERING ANALYSIS OF SPUR GEAR

6.1 INTRODUCTION

Tooth is generated during gear shaping, due to combined rotation and vertical movement of cutter. It leads to generation of trochoidal fillet. For coarse pitch gear, value of root fillet radius is defined as 0.3 times module. For fine pitch gear where module is less than 1.27, the value is not defined in the literature.

Bending strength of the tooth depends upon the root fillet radius, in this chapter an attempt has been made to analyze effect of variation of tooth root fillet radius on Von-Mises stress, strain and deformation by using Autocad, Pro-E and ANSYS software. Material chosen in this analysis is MMC consisting of aluminum as matrix material and silicon carbide as reinforcement. The strength of aluminum silicon carbide MMC is in between GFRP and steel. This material is light in weight and corrosion resistant.

The designer is always faced with the problem of stress concentration, at sections having abrupt change of shape. Root of the gear tooth is the area where stress concentration occurs. The best that can be done is to minimize its effects. The general guideline, for designing of minimum stress concentration, is to avoid sharp corners completely and to provide largest possible transition radius between surfaces of different contours. Checking the gear for strength is a difficult task than to check run out, profile, lead, pitch variation and misalignment.

Fillet radius dimensions are rarely defined on the drawing; geometric and dimensional constraints are insufficient to define the root fillet radius of gears. In this chapter an attempt has been made to check the bending strength, deformation, strain, factor of safety with respect to root fillet radius. The mechanical properties of aluminium silicon carbide metal matrix taken is density-2.88 gm/cc, ultimate tensile strength-690 MPa, Yield tensile strength – 487 MPa, Poisson's ratio – 0.3 for finite element analysis [111] .

6.2 FILLET ROOT RADIUS VARIATION ON METAL MATRIX COMPOSITE SPUR GEAR

Al-Sic MMC has been taken as a gear material to develop a finite element model for analysis. Investigation is done on the effect of tooth fillet radius variation on stress, strain, deflection and factor of safety. Composite material has gained priority among material with the integral property of light weight and strength. Aluminium silicon carbide MMC is the best option in case of gears, where there is the requirement of weight reduction, strength enhancement ,corrosion resistance and better life of component.

Spur gear is characterized by tooth breakage due to bending and surface failure; out of this, tooth strength in bending is critical; tooth absence disables the gearbox, but pitting of the surface gives sufficient time for its replacement. During working, maximum stress is generated at the root; as it is the end of tooth which acts as the cantilever.

Undercutting is the phenomenon which occurs when dedendum is large enough to extend below the base circle resulting in profile which is not an involute at the fillet radius. This can be avoided by limiting the minimum number of teeth to 17 for the pinion with 20 degree pressure angle. The fillet radius which is generated automatically due to the cutting motion of cutter is known as trochoidal fillet. Its value is taken as 0.3 times module for coarse pitch gear and for fine pitch gear its value is not defined.

Through a lot of work has done on fillet radius of spur gear but its value for fine pitch gear value is not defined so far. Here a finite element analysis model has been developed, in which by putting the different value of tooth fillet radius: the Von-Mises stress, strain, deformation can be obtained. At ANSYS work bench through finite element analysis, factor of safety for spur gear can be calculated.

It is evident that researchers have extensively studied the root fillet radius of gears and have shown that root fillet improves the properties of gears. However, to the best of the authors' knowledge, no literature is available that deals with the method of finding optimum tooth fillet radius for Aluminium silicon carbide MMC material spur gear on

Ansys workbench. Thus in the present study, Finite element analysis model has been developed to find out the gear capability based on fillet radius. The load is applied on teeth for varying fillet radius and comparisons are done for the Von-Mises stress, strain, deformation and factor of safety.

6.3 CONSTRUCTION OF COMPUTER AIDED DESIGN MODEL

Analysis of gear problems includes making of two dimensional drawing, making solid model and analyzing mechanical properties. Autocad, Pro E, and Ansys workbench has been used for analysis.

The capacity of tooth to withstand and successfully transfer it depends upon material, tooth dimensions, environment, lubrication etc. There are two methods to determine tooth capability first is to test practically second is to find out through finite element analysis which is explained in this chapter. Along with this some cases are there where root fillet radius is not defined for example fine pitch gear. In the past destructive testing is done which includes making special hob cutters and testing the specimen which is the costly and time consuming process. In this chapter using finite element method it is possible to find out stress, deflection, strain and deformation for different values of tooth fillet radius.

The proposed model is constructed by taking the module, number of teeth and face width as fundamental specification. Detailed dimensions like addendum, dedendum, pressure angle, tooth thickness , pitch circle diameter, outer diameter, root diameter, base circle diameter, circular pitch are given in Table 6.1. Pitch circle diameter is the location where actual rotation takes place whereas addendum and dedendum is the region where sliding takes place between mating surfaces of gear and pinion.

It is evident that if tooth strength could be increased based on fillet radius then it is possible to reduce module to transfer same load resulting in low sliding in addendum and dedendum region and tooth would have more life in wear. Static analysis is used to determine the displacement, stresses, strains and forces in fine pitch gears due to loads. A static analysis can be either linear or non linear. In our present work we consider linear static analysis.

The procedure for static analysis consists of three main steps

(i) Building the model
(ii) Obtaining the solution
(iii)Reviewing the results.

Following Software's has been used:

(i) AUTOCAD-2010
(ii) PRO-E 5.0
(iii) ANSYS-18.1

Table 6.1 Specification of 17 teeth spur gear

S.No.	Description	Formula	value
1	Number of teeth (Nos)	z=d/m	17
2	Module (mm)	m=d/z	1.25
3	Addendum (mm)	h_a=1m	1.25
4	Dedendum (mm)	h_f=1.25m	1.562
5	Pressure angle (degree)	-	20
6	Tooth thickness (mm)	t = 1.6m	1.96
7	Tooth height (mm)	h= h_a+ h_f	2.812
8	Face width (mm)	Required value	10
9	Pitch circle diameter (mm)	d = mz	21.25
10	Root diameter (mm)	d_f= d-2 h_f	18.12
11	Outside diameter (mm)	d_a =d+2 h_a	23.75
12	Base circle diameter (mm)	d_b=d cos α	19.96

Auto CAD is used for making two dimensional drawings of gears, mould and fixtures developed during the research.

6.4 SELECTION OF METHOD AND PROCESS

Following modes were used during finite element analysis:-

(i) Interactive Mode

This is the default mode in ANSYS. It allows working with menus and dialog boxes for online help and tools to create models in the graphics window.

(ii) Batch Mode

Batch mode is to execute a file of commands in the ANSYS program. It enables not to interact with the program, such as, during the solution phase of analysis.

6.5 FINITE ELEMENT ANALYSIS

During the finite element analysis of fine pitch spur gear, a systematic process is followed for reaching final values of design parameters. It includes dividing the spur gear into small elements and effect of load is studied on one tiny element. As per the basic concept of FEM the gear to be analyzed is considered as an assemblage of discrete pieces called "Elements" that are connected together at a finite number of points (or) nodes. The finite element is a geometrically simplified representation of a small part of the physical structure which includes following steps:-

(i) Divide the gear in which analysis is to be carried out into small elements.
(ii) Isolating one of the gear elements from each type and get the property of it.
(iii) Assembling the gear finite elements to get the property of whole gear.
(iv) Finite-element discretization of gear: First the continuous region (i.e. the circle) is represented as a collection of a finite number ' n' of sub regions say triangles. This is called discretization of the gear by triangles. Each sub region is called as an "element".

6.5.1 Preprocessing

The preprocessing is a program that processes the gear input data to produce the output that is used as input to the subsequent phase (solution). Following are the input data that needs to be given to the preprocessor:

(i) Type of gear analysis that is structural.
(ii) Gear element type.
(iii) Gear real constraints.
(iv) Gear material properties.
(v) Gear geometric model.
(vi) Gear meshed model.
(vii) Gear loadings and boundary conditions.

(viii) The gear input data will be preprocessed for the output data and preprocessor will generate the data files automatically with the help of GUI. These data files will be used by the subsequent

6.5.2 Gear solution

Gear solution phase is completely automatic. The FEA software generates the element matrices, computes nodal values, derivatives and stores the result data in files. These files are further used by the subsequent post processing phase to review and analyze the results through the graphic display and tabular listings.

6.5.3 Gear post processing

The output from the gear solution phase is in the numerical form and consists of nodal values of the field variable and its derivatives. The postprocessor processes the result data and displays them in graphical form to check or analyze the result.

The graphical output gives the detailed information about the required result data. The postprocessor phase is automatic and generates the graphical output in the stress, strain, deformation form specified in the pre processing phase. Result viewer and plot result are used for postprocessing in gear problem.

6.5.4 Key Assumptions in finite element analysis of gear

There are four assumptions taken that affect the quality of the gear solution and considered for finite element analysis. These assumptions are not comprehensive but cover a wide variety of situations applicable to the gear problem.

6.5.4.1 Assumptions related to gear geometry

(i) Displacement values of gear will be small so that a linear solution is valid for gear.

(ii) Stress behavior outside the area of interest has been left, so the geometric simplifications of gear in those areas will not affect the outcome.

(iii) Only internal fillets in the area of interest will be included in the gear solution.

(iv) Local behavior at the corners and intersection of geometries is of primary interest therefore no special modeling of these areas is required for gear.

(v) Decorative external features will be assumed insignificant for the stiffness and performance of the part will be omitted from the gear model.

(vi) The variation in mass due to the suppressed features is negligible in gear.

6.5.4.2 Assumptions related to gear material properties

(i) Gear material properties will remain in the linear region and nonlinear behavior of the material property cannot be accepted.

(ii) Gear material properties are not affected by the load rate.

(iii) The gear is free from surface imperfections that can produce stress risers.

(iv) All gear simulations will assume room temperature, unless otherwise specified.

(v) The effects of relative humidity or water absorption on gear material used will be neglected.

(vi) No compensation will be made to account for the effect of chemicals, corrosives, wears or other factors that may have an impact on the long term structural integrity of gear.

6.5.4.3 Assumptions related to gear boundary condition

As shown in Figure 6.3, gear internal diamenter is fixed and load of 750 N is applied on the pitch circle diameter.Following assumption has been taken into consideration:-

(i) Gear displacements will be small so that the magnitude, orientation and distribution of the load remain constant throughout the process of deformation.

(ii) Gear frictional loss in the system is considered to be negligible.

(iii) All interfacing gear components will be assumed rigid.

(iv) The portion of the gear structure being studied is assumed as a separate part from the rest of the system therefore any reaction or input from the adjacent features is neglected.

6.6 PRECUATIONS TAKEN DURING GEAR FINITE ELEMENT ANALYSIS FOR ACCURATE RESULTS

(i) The gear model contains fundamental flaws such as parts missing, not connected is inappropriate and is taken care.

(ii) The gear model is properly represented as built in the engineering drawings.

(iii) The loads and boundary conditions are represented properly
(iv) One type of analysis was done at one time.
(v) Proper design codes are used.
(vi) Computer with high RAM is used for fine meshing, run nonlinear analysis and review results in sufficient detail.

6.7 RESULTS AFTER SOLUTION PHASE IN FINITE ELEMENT ANALYSIS

Before CAD, manufactures and designers would have to build prototypes of automobiles, buildings, computer chips, and other products for testing. CAD technology, however, allows to rapidly produce a computer generated prototype and then test and analyze the prototype under a variety of simulated conditions. PRO E has been chosen to make solid model of gear. It includes making the two dimensional detailed drawing in autoCAD and making the solid model in proE, then model is exported to ANSYS workbench by file → import → IGES.

After completion of the finite element model it has to constrain and load has to be applied to the model. During the construction and verification stages of the model it is viewed from different angles.Pre processor is used having these capabilities. By windowing feature pre processor allows to enlarge a specific area of the model for clarity and details. Pre processor also provides features like smoothness, scaling, regions, active set, etc for efficient model viewing and editing.

All elements are defined by nodes, which have only their location defined. In the case of plate and shell elements there is no indication of thickness. This thickness can be given as element property. Property tables for a particular property set 1-D have to be input. Different types of gears have different properties like cross sectional area, moment of inertia, thickness, spring stiffness. For linear static analysis, modules of elasticity and Poisson’s ratio need to be provided.

The solution phase deals with the solution of the problem according to the problem definitions. All the tedious work of formulating and assembling of matrices are done by the computer and finally displacements, stress values are given as output. It is a powerful user friendly postprocessing program using interactive color graphics. It has extensive plotting features for displaying the results obtained from the finite element analysis. One picture of the analysis results can often reveal in seconds which take hour to assess from a numerical output in tabular form.

It is possible to find out the important aspects of the results that could be easily missed in a stack of numerical data. Employing state of art image enhancement technique it is possible to find out contours of stresses, displacements deform geometric plots, animated deformed shapes, time-history plot, solid sectioning, hidden line plot, light source, shaded plot, boundary line plot.

The entire range of post processing options of different types of analysis can be accessed through the common mode there by giving flexibility and convenience.

Gear specification and analysis title used PREP7 to define the element types, element real constants, material properties and model geometry. Element type linear and non-linear structural are allowed. The ANSYS elements library contains over 80 different element types. A unique number and prefix identify of each element type like BEAM 94, PLANE 71, SOLID 96 and PIPE 16 are available. In the gear case SOLID 186 element type is chosen.

Young's modulus (EX) defined for a gear static analysis. To apply inertia loads (such as gravity) mass properties such as density (DENS) has been defined during gear analysis. In the present case its value is 115 GPa and 2.88 gm / cc for aluminum silicon carbide MMC.

To define the gear analysis type and options, apply loads for the finite element solution following three phases are needed:-

(i) Pre-processor phase
(ii) Solution phase
(iii)Post-processor phase

Pre processor has been used so that the same gear program is available on micro, mini, super-mini and mainframe computer system. This slows easy transfer of models from one system to other. Pre processor works as builder to prepare the FE (finite element) model and input data.

The solution phase utilizes the input data developed by the pre processor, prepares the solution according to the input requirement of stress, strain and deformation. It creates input files on the screen in the form of contours.

There are four different geometric entities in pre processor namely key points, lines, area and volumes. These entities are used to obtain the geometric representation of the gear. All the entities are independent on each other other and have unique identification labels.

Two different methods are used to generate a model:

(i) Direct generation.
(ii) Solid modeling

With solid modeling geometric boundaries of the model has been fixed, established control over the size and desired shape of the elements and then instructed ANSYS program to generate all the nodes and elements automatically. By contrast, with the direct generation method, it is possible to determine the location of every node and size shape and connectivity of every element prior to defining these entities in the ANSYS model. Although, some automatic data generation is taken (by using commands such as FILL, NGEN, EGEN etc) the direct generation method essentially a hands on numerical method required to keep track of all the node numbers during development of the finite element mesh.

In the finite element analysis gear to be analyzed considered to be an assemblage of discrete pieces called elements, which are connected, together at a finite number of points called Nodes. After fixing the internal diameter of gear load is applied at pitch circle diameter with 20^0 pressure angle. Load gets transferred to node and elements.

The maximum amount of time in a finite element analysis is spent on generating elements and nodal data. Pre processor generates nodes and elements automatically at the same time allowing control over size and number of elements. There are various types of elements that can be mapped or generated on various geometric entities.

The elements developed by various automatic element generation capabilities of pre processor can be checked by element characteristics that may need to be verified before the finite element analysis for connectivity, distortion-index etc. Automatic mesh generating capabilities of pre processor are used rather than defining the nodes individually. Required nodes defined by allocations and by translating the existing nodes.

Following steps are taken to do the finite element analysis:-

Step 1:- Element definition.

Go to ansys main menu → element type → add/edit/Delete, select→ element type ,typ1 SOLID 187 → add →ELIST command. After giving the element definition the model get divided into this equal spaced finite element.

Step 2:- Material properties.

Go to mechanical utility menu → pre-processor → material properties → Define material model behavior → material modes available → structural → linear → Elastic → Isotropic → Linear Isotropic material properties for material number 1,put value of Poisson's ratio 0.3,density 2.88 gm/cc, youngs modulus 1.15 x 10^{+05},tensile yield strength 487 MPa, Tensile ultimate strength 690 MPa.

Step 3:- Meshing the spur gear.

Define the meshing properties by going to ansys main menu → meshing → mesh tools and put the element edge length of 1mm in element sizes on picked lines → yes in KYNDIV SIZE, NDIV can be changed option.

Wait for the meshing to complete. It can take few minutes, after mesh generation → see the partial view meshing → closer view meshing → color element plot in case of any problem → repeat the process → see the element numbers → colors of sections → check the uniformity of it. Meshing details are given in Figure 6.3.

Element size is 0.5 mm, minimum edge length is 0.35 mm, Number of nodes are 214279 and numbers of elements are 47540.

Step 4:- Fillet radius.

Models are modified by changing the fillet radius of values 0.1mm → 0.2mm, → 0.3mm → 0.4mm → 0.5mm. After this, the steps of 1 upto 3 are repeated for obtaining the mesh.

After this boundary conditions are applied by keeping the center of the gear fixed.Apply load of 750N, at the pitch circle diameter, of the single tooth.

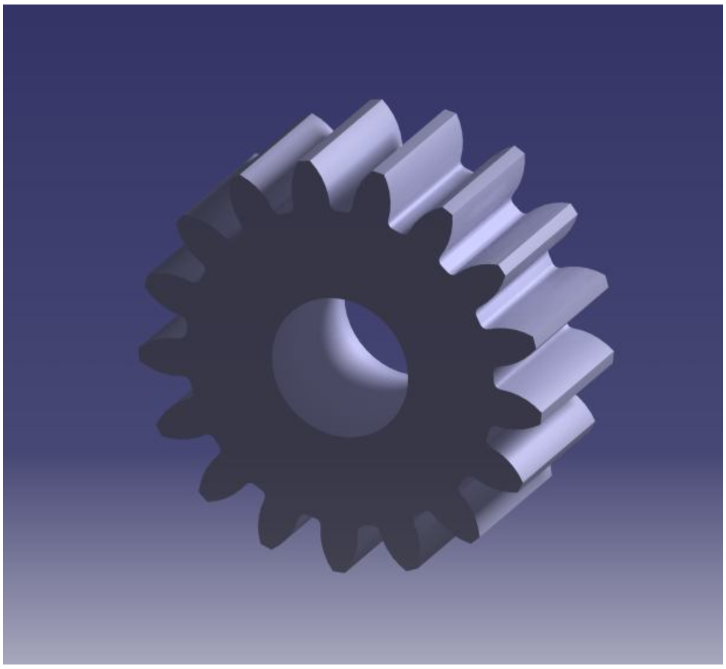

Figure 6.1 Fine pitch spur gear

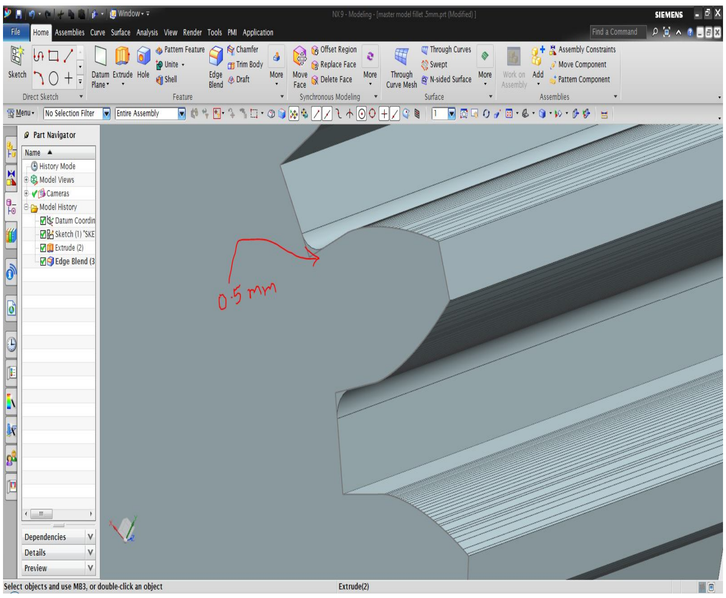

Figure 6.2 Tooth profile of fine pitch spur gear

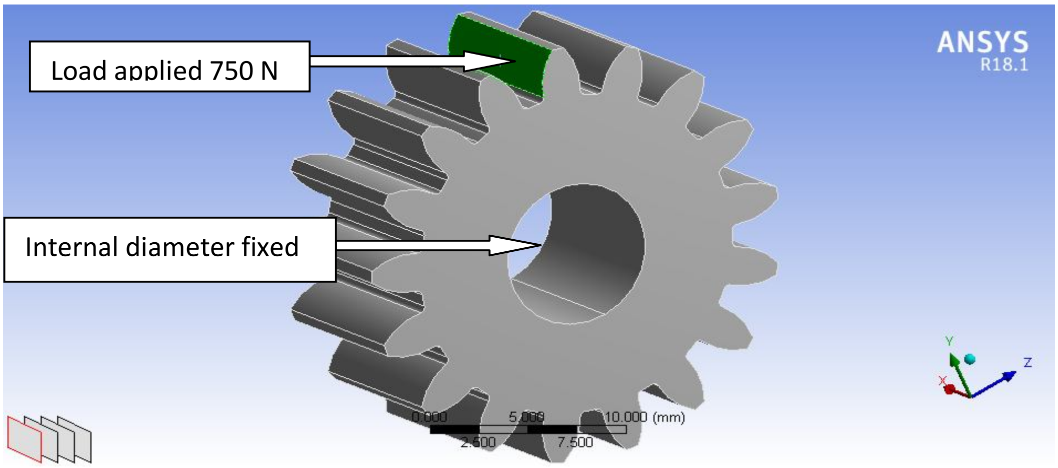

Figure 6.3 Boundary condition

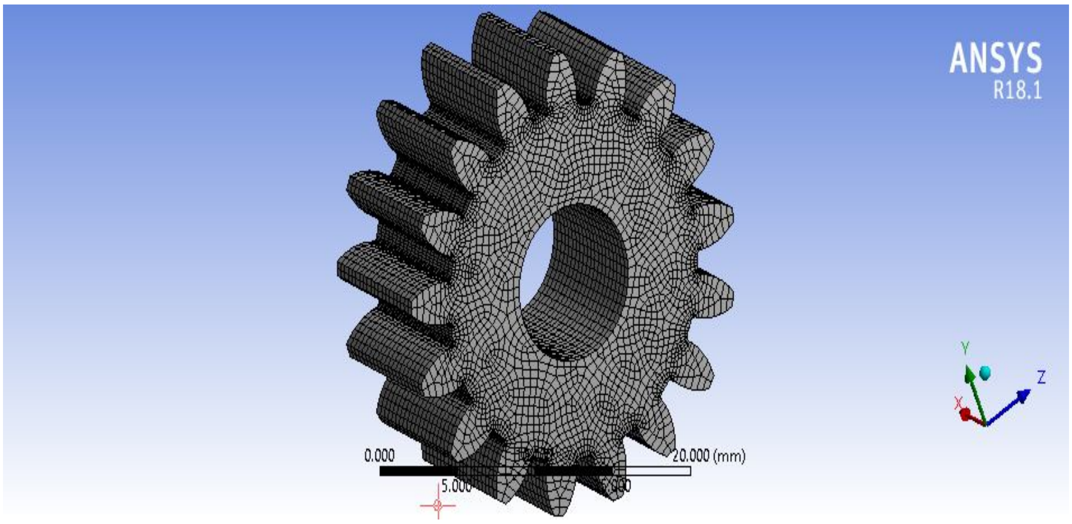

Figure 6.4 Meshing details of gear

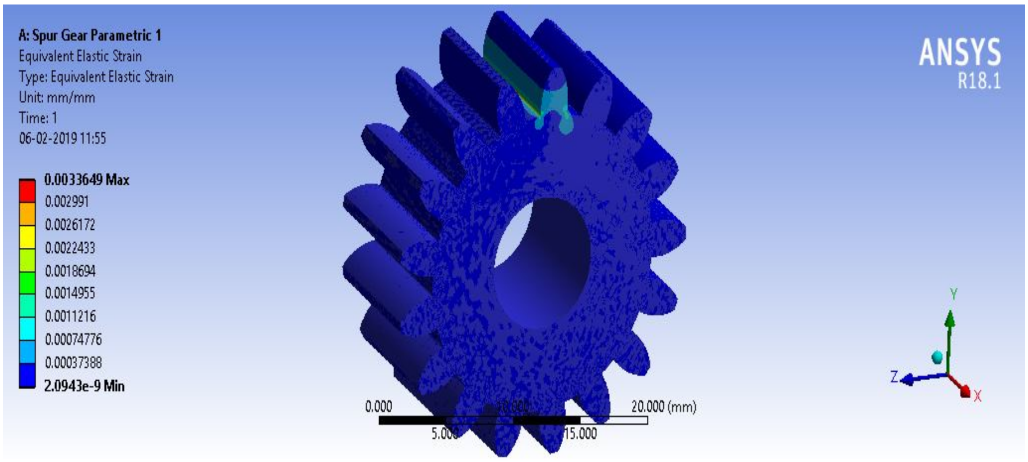

Figure 6.5 Elastic strain at 0.1 mm root fillet radius

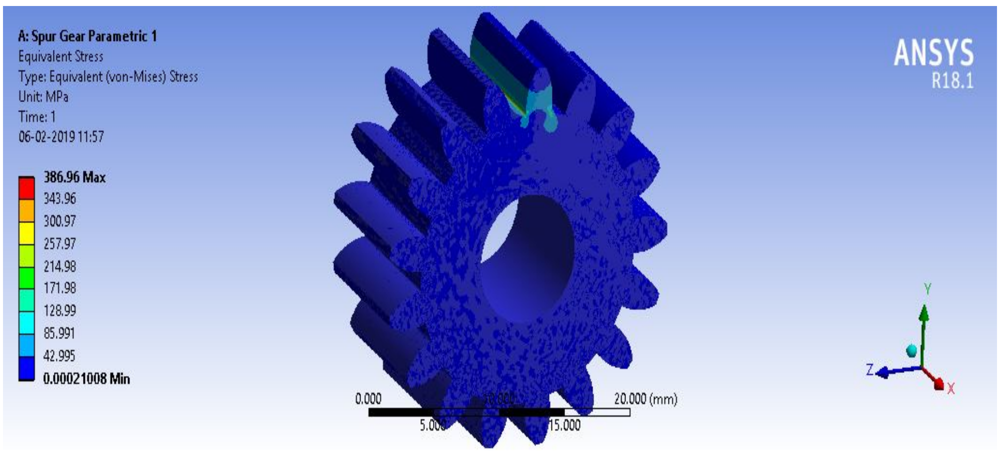

Figure 6.6 Von-Mises stress at 0.1 mm root fillet radius

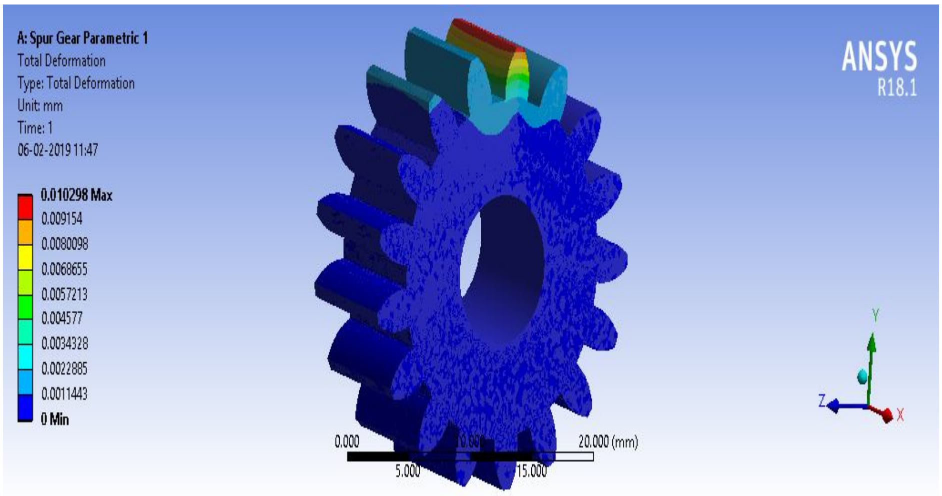

Figure 6.7 Deformation at 0.1 mm root fillet radius

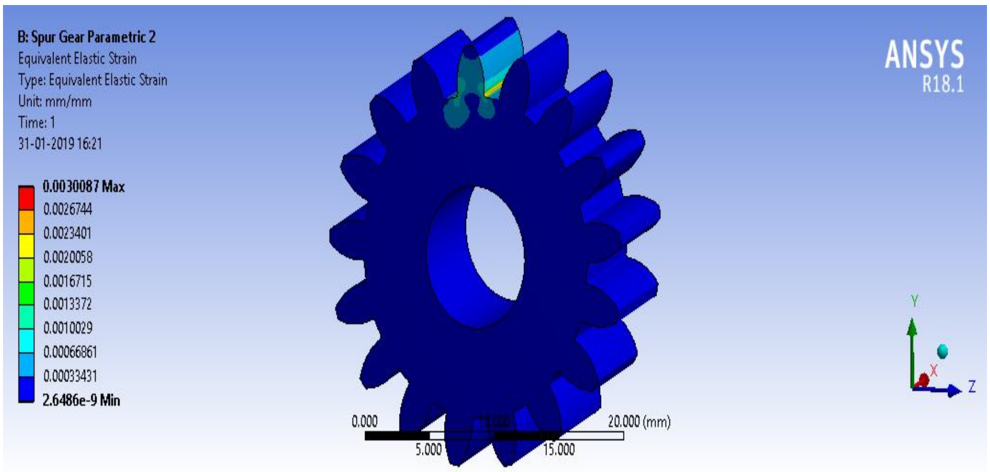

Figure 6.8 Elastic strain at 0.2 mm root fillet radius

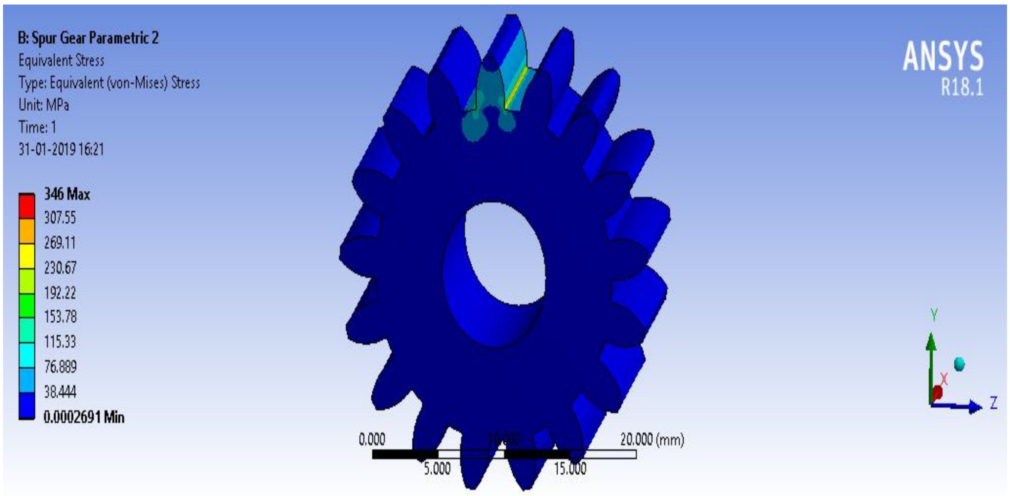

Figure 6.9 Von-Mises stress at 0.2 mm root fillet radius

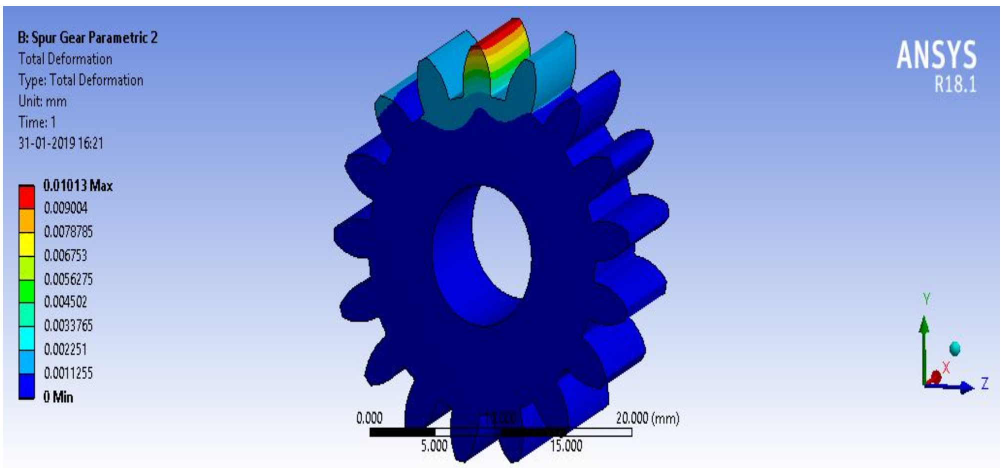

Figure 6.10 Deformation at 0.2 mm root fillet radius

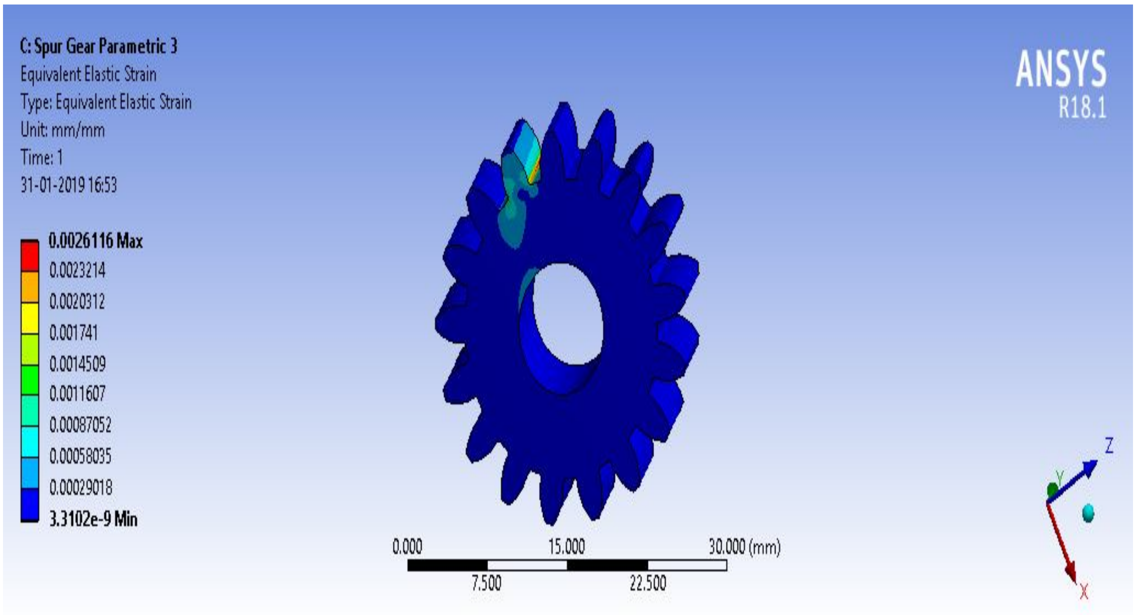

Figure 6.11 Elastic strain at 0.3 mm root fillet radius

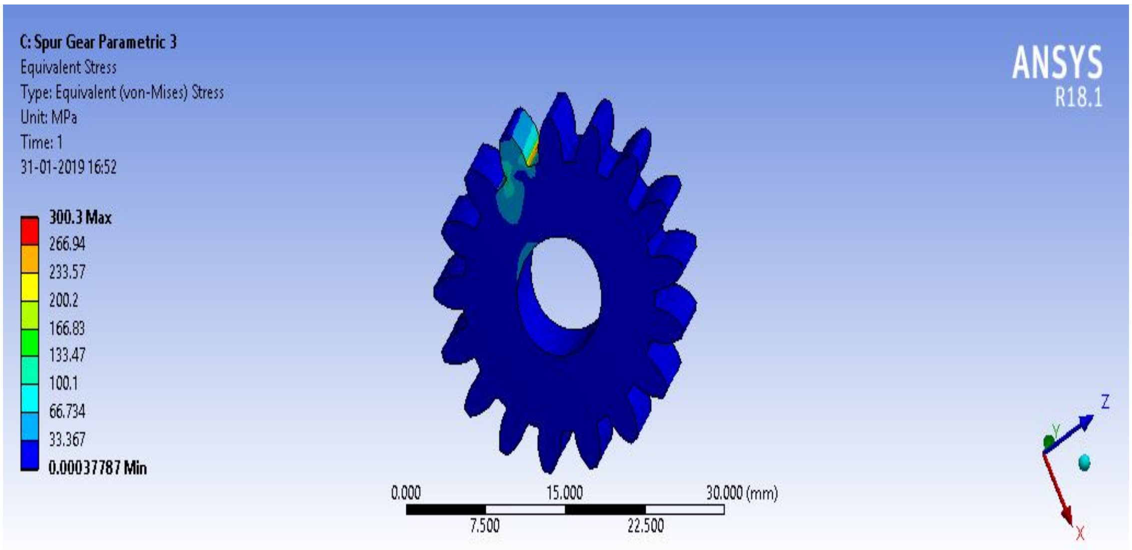

Figure 6.12 Von-Mises stress at 0.3 mm root fillet radius

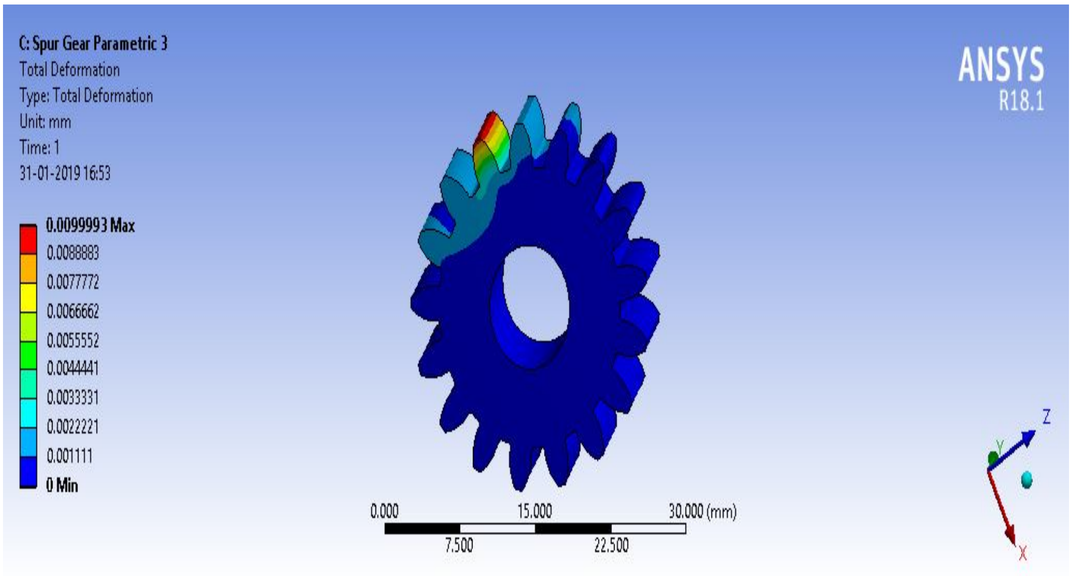

Figure 6.13 Deformation at 0.3 mm root fillet radius

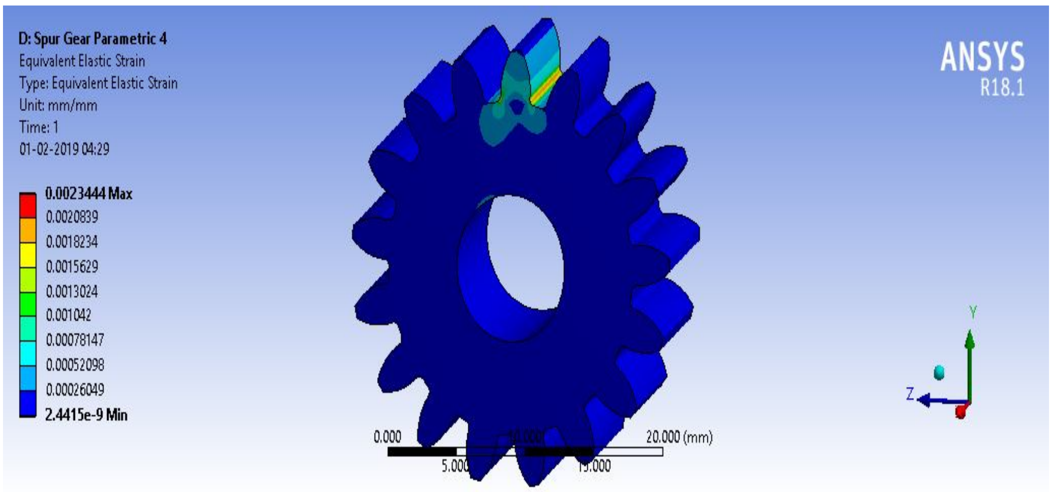

Figure 6.14 Elastic strain at 0.4 mm root fillet radius

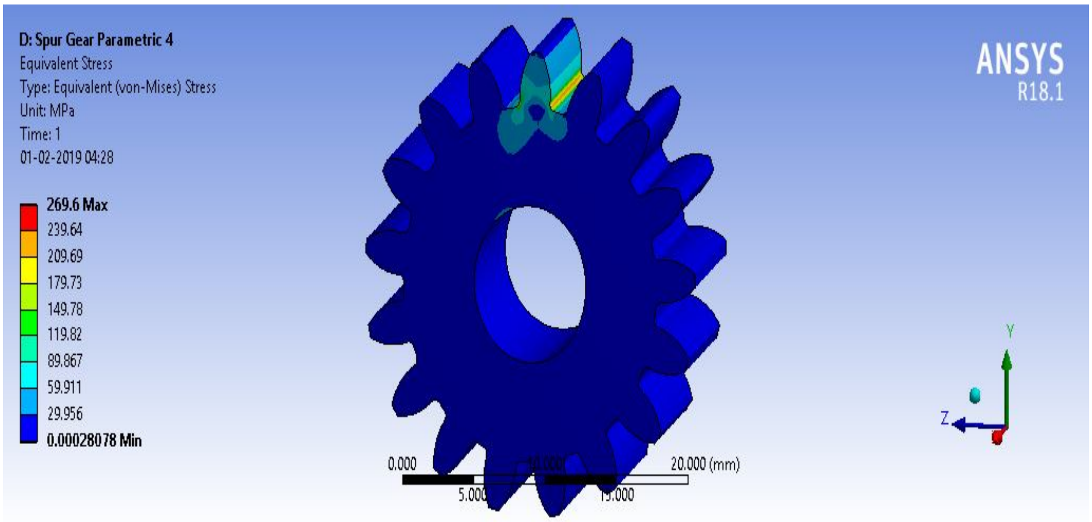

Figure 6.15 Von-Mises stress at 0.4 mm root fillet radius

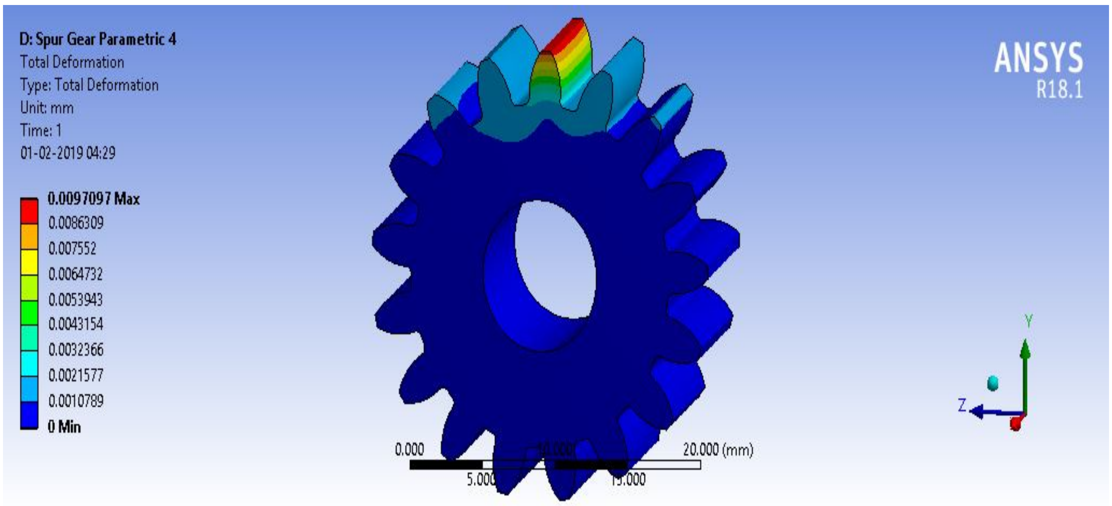

Figure 6.16 Deformation at 0.4 mm root fillet radius

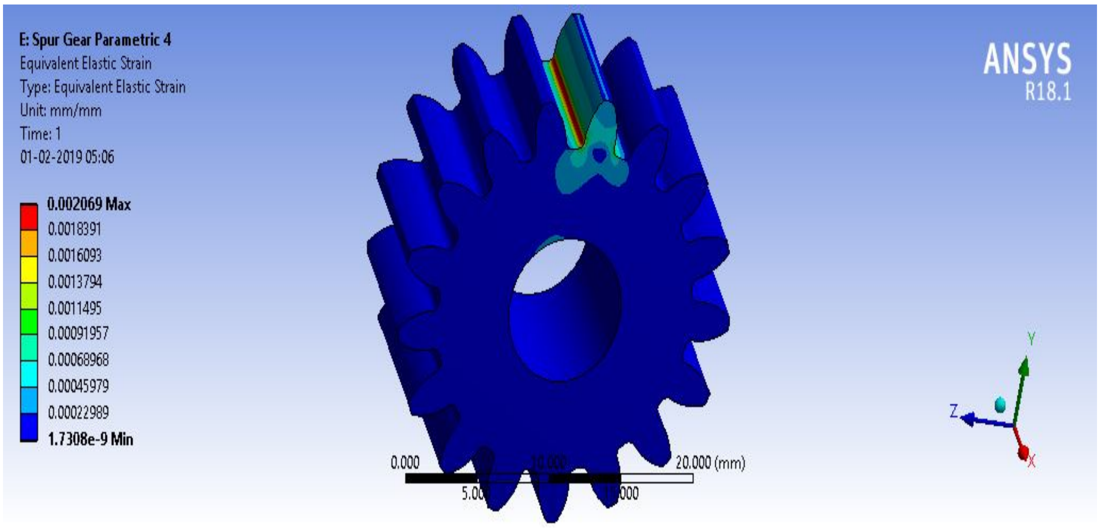

Figure 6.17 Elastic strain at 0.5 mm root fillet radius

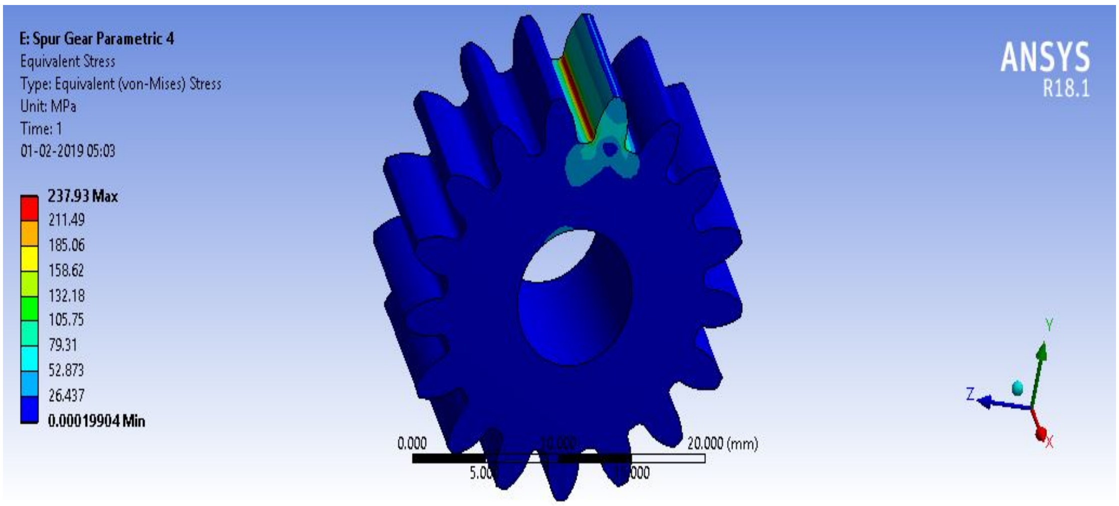

Figure 6.18 Von-Mises stress at 0.5 mm root fillet radiu

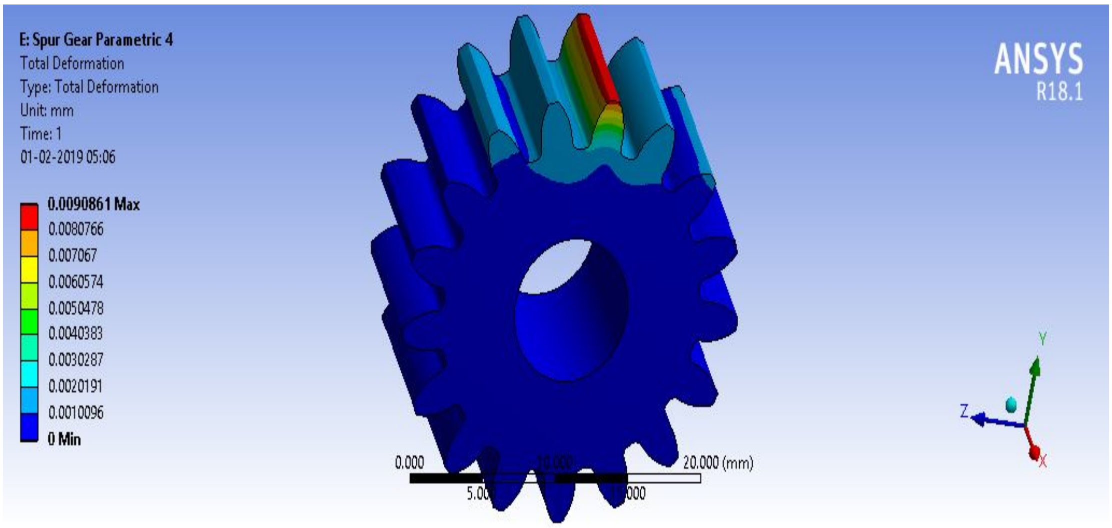

Figure 6.19 Deformation at 0.5 mm root fillet radius

6.8 ANALYZED RESULTS

After applying boundary conditions following are the results when load of 750 N is applied for fillet radius of 0.1 mm:-

(i) Equivalent elastic strain is 0.0033649 mm/mm.

(ii) Von-Mises stress is 386.96 MPa.

(iii) Total deformation is 0.010298 mm.

After applying boundary conditions following are the results when load of 750 N is applied for fillet radius of 0.2 mm:-

(i) Equivalent elastic strain is 0.0030087 mm/mm.

(ii) Von-Mises stress is 346 MPa.

(iii) Total deformation is 0.01013 mm.

After applying boundary conditions following are the results when load of 750 N is applied for fillet radius of 0.3 mm:-

(i) Equivalent elastic strain is 0.0026116 mm/mm.

(ii) Von-Mises stress is 300.3 MPa.

(iii) Total deformation is 0.0099993 mm.

After applying boundary conditions following are the results when load of 750 N is applied for fillet radius of 0.4 mm:-

(i) Equivalent elastic strain is 0.0023444 mm/mm.
(ii) Von-Mises stress is 269.6 MPa.
(iii)Total deformation is 0.0097097 mm.

After applying boundary conditions following are the results when load of 750 N is applied for fillet radius of 0.5 mm:-

(i) Equivalent elastic strain is 0.002069 mm/mm.
(ii) Von-Mises stress is 237.93 MPa.
(iii)Total deformation is 0.0090861 mm.

In the post processing phase, load of 750 N is applied at the pitch circle diameter. For the fillet radius of 0.1 mm, Von-Mises stress developed is 386.96 MPa shown in Figure 6.4, strain is 0.0033649 mm shown in Figure 6.3; deformation is 0.010298 mm shown in Figure 6.5. The outcome from the spur gear analysis of 0.2 mm fillet radius: Von-Mises stress is 346 MPa shown in the Figure 6.7; strain is 0.0030087 mm shown in Figure 6.6, deformation is 0.01013 mm depicted in Figure 6.8. For 0.3 mm fillet radius: Von-Mises stress is 300.3 MPa shown in Figure 6.10, strain is 0.0026116 mm shown in Figure 6.9, deformation is 0.0099993 shown in Figure 6.11.By taking fillet radius 0.4mm: Von-Mises stress is 269.6 MPa shown in Figure 6.13,strain is 0.0023444 mm shown in Figure 6.12, deformation is 0.0097097 mm shown in Figure 6.14 and varying the fillet radius to 0.5 mm: Von-Mises stress is 237.93 MPa shown in Figure 6.16, strain is 0.002069 mm shown in Figure 6.15, deformation is 0.0090861 shown in Figure 6.17.

6.8.1 Effect of variation of root fillet radius on Von-Mises stress

The increase in value of fillet radius is restrained by the fact that there should not be any interference between gears when teeth are in contact. The interference is likely not to happen when the fillet radius is too high. When the gear is cut with the standard gear shaper, the cutting tool will interfere with the portion of tooth below base circle and will cut away the interfering material. This will result in undercutting which weakens the tooth by removing material.

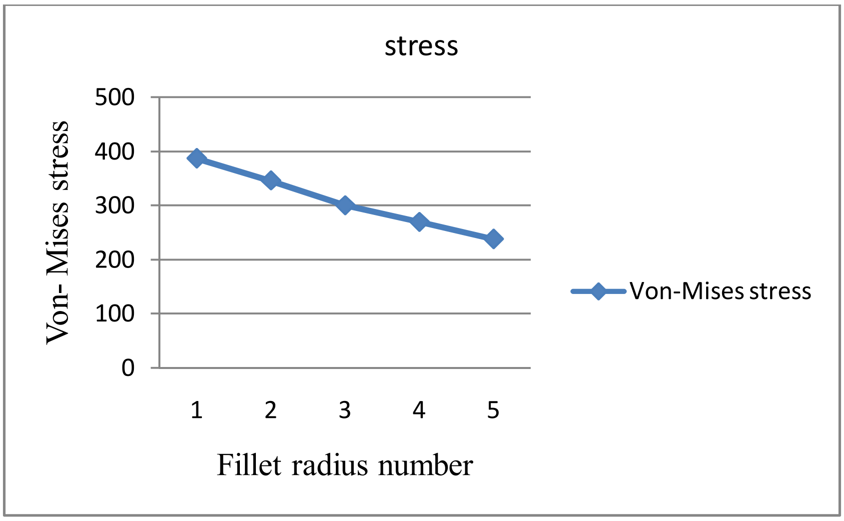

Figure 6.20 Effect of variation of root fillet radius on stress

The fillet radius increments have a positive effect on the design parameters of spur gears but it is restrained by interference and undercutting.It is evident from Figure 6.18 shows that with the increase in fillet radius, the Von- Mises stress goes on decreasing from the magnitude of 41.85 MPa to 27.89 MPa.

6.8.2 Effect of variation of root fillet radius on elastic strain

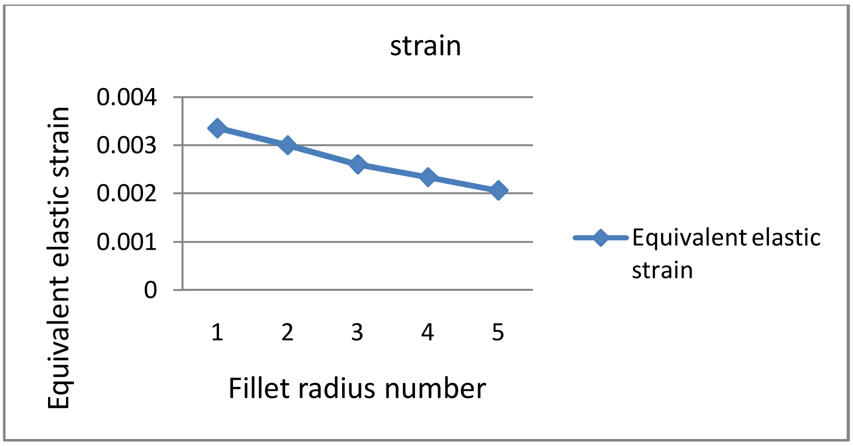

Figure 6.21 Effect of variation of root fillet radius on strain

As the fillet radius of the gear tooth changes its value from 0.1mm to 0.5 mm the strain starts decreasing from the maximum value to minimum value of 0.00047.Figure 6.19 shows the graphical representation of strain verses fillet radius.

6.8.3 Effect of variation of root fillet radius on total deformation

Deformation starts decreasing with the increase of tooth fillet radius,it enhances the torque transmission, reduces the noise and vibration, because of the increase in rigidity of the tooth, which acts as a cantilever beam. Figure 6.20 shows the decline of deformation with respect to fillet radius.

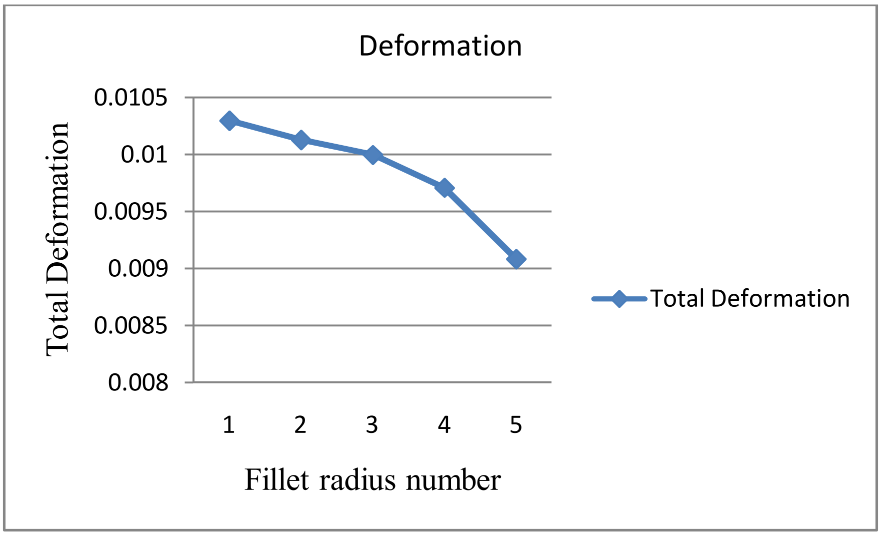

Figure 6.22 Effect of variation of root fillet radius on deformation

6.8.4 Effect of variation of root fillet radius on factor of safety

Factor of safety (FOS) starts increasing with the increase of tooth fillet radius. It increases the load carrying capacity of tooth, reduces the tooth detrioration, sliding friction between addendum and dedendum of mating teeth. Figure 6.21 shows the increase in FOS with respect to fillet radius.

Equation 6.1 is used to calculate FOS, where yield stress from experimental results is 487 Mpa and developed load stress is Von-Mises stress from Ansys software.Table 6.3 shows effect of variation of tooth root fillet radius on von mises stress, strain and deformation.

Optimum condition of root fillet radius achieved is at 0.3 for which Von Mises stress is 300.3 MPa. In the case of gears if number of teeth is below 17 undercutting takes place at root fillet radius and its value is defined as 0.3 times module for coarse pitch gear. For fine pitch gear its value is not defined.

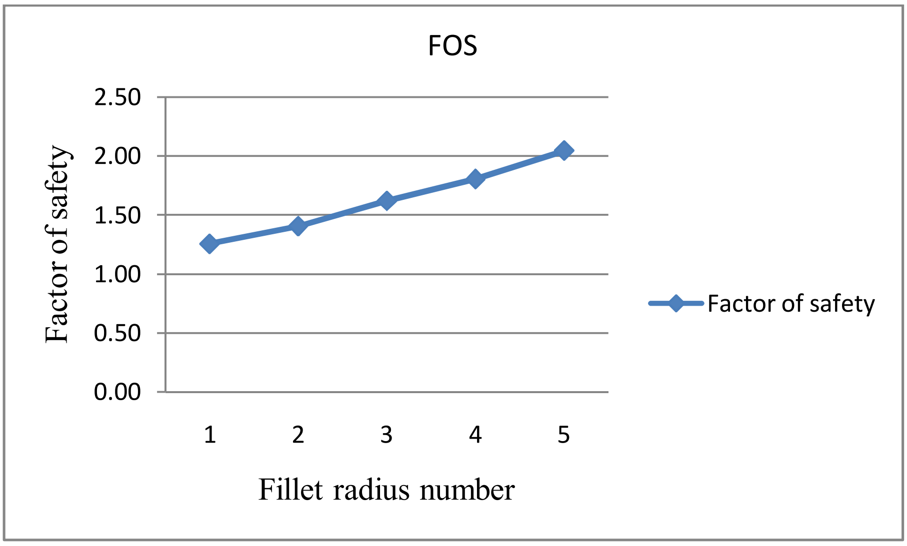

Figure 6.23 Effect of variation of root fillet radius on factor of safety

FOS = Yield stress from experimental results/ Developed load stress (6.1)

Table 6.2 Effect of root fillet radius on fine pitch spur gear

Fillet radius number	Fillet radius (mm)	Von-Mises stress (MPa)	Equivalent elastic strain (mm/mm)	Total Deformation (mm)	FOS
1	0.1	386.96	0.0033649	0.010298	1.26
2	0.2	346	0.0030087	0.01013	1.41
3	0.3	300.3	0.0026116	0.0099993	1.62
4	0.4	269.6	0.0023444	0.0097097	1.81
5	0.5	237.93	0.002069	0.0090861	2.05

Here module of 1.25 mm has been taken as fine pitch gear, for which value of root fillet radius is not defined. By analysis root fillet radius is varied from 0.1 to 0.5 mm. As per the coarse gear standard formula its value coming is 0.375 mm to avoid undercutting, to be on safer side optimum value of 0.3 has been chosen for which factor of safety is 1.62.

6.9 SUMMARY

This chapter shows that in the case of fine pitch gear as the fillet radius of gear tooth is increased. Its bending strength starts increasing. This effect could also be utilized in coarse pitch gear where module can be reduced by increasing the tooth fillet radius, resulting in small tooth and decrease in contact stresses at sliding portion of addendum and dedendum region. A step-by-step procedure in gear design of composite material has been developed on Ansys workbench. Variation of tooth fillet radius on the stress, strain and deformation have been studied for fine pitch gears and found that increasing fillet radius reduces stress, strain and deformation for MMC material.

CHAPTER 7

NOISE ANALYSIS AND SHOT PEENING OF SPUR GEAR

7.1 INTRODUCTION

Noisy gear trains have been a common problem for gear designers for a long time. With the increase of demands for smaller gear boxes transmitting more power at higher speeds. Incumbent demands for greater efficiency and gear engineers are always searching for new ways to reduce vibration and limit noise. In this chapter comparative analysis of noise in between spur gear of steel, MMC and GFRP has been done. Material selection can play an important role in reducing the gear noise. Specifying tighter dimensional tolerances or redesigning the gear are the most common approaches, design engineers chose to minimize noise. But it add cost to the finished part and strain the relationship between the machine shop and the end user. Though a lot of work has been done on noise reduction in spur gears.A little work is found for experimental analysis of the effect of noise in spur gears using steel, MMC and GFRP spur gear. During machining and cold working processes of gears, tensile stresses get develop on surface. It results in low fatigue life. Since useful life of the gear is important for power transmission it should be increased. Shot peening is the process which generates residual compressive stress on top most layer of gear and increases fatigue life. Upper layer becomes hard and gear life increased against contact stresses. It is bombarding of surface of metal with hard material shots. In this chapter MMC is shot peened and GFRP gear are sand blasted. Sand blasting improves the surface finish and provides the surface to hold protective coatings for longer period. The mechanical properties of AISI 4140 annealed steels is having ultimate tensile strength of 655 MPa, Yield strength of 417 MPa, elongation 25.7%, reduction in area 57%, Brinell hardness of 197 HB, izod impact strength of 54.5J

7.2 METHODOLOGY

Gear testing consists of pinion with 24 teeth and gear with 48 teeth .It is rotated by 12V, DC motor. The speed of revolution of gear is recorded by non-contact type tachometer. The module, number of teeth, face width and other parameters are given in the Table 7.1.

Table 7.1 Specification of 48 teeth gear for noise testing

S.No.	Description	Symbol	Formula	Gear
1	Number of teeth (nos)	z	z=d/m	48
2	Module (mm)	m	m=d/z	2
3	Addendum (mm)	h_a	h_a=1m	2
4	Dedendum (mm)	h_f	h_f=1.25m	2.5
5	Pressure angle (degree)	α	Degree	20
6	Tooth thickness (mm)	t	t=1.6m	3.2
7	Tooth height (mm)	h	$h=h_a+h_f$	4.5
8	Face width (mm)	w	w=5m	10
9	Root diameter (mm)	d_f	$d_f=d-2h_f$	91
10	Outside diameter (mm)	d_a	$d_a=d+2h_a$	100
11	Pitch circle diameter (mm)	d	d=mz	96
12	Base circle diameter (mm)	d_b	$d_b = d \cos \alpha$	90.2

Table 7.2 Specification of 24 teeth gear for noise testing

S.No.	Description	Symbol	Formula	Pinion
1	Number of teeth (nos)	z	z=d/m	24
2	Module (mm)	m	m=d/z	2
3	Addendum (mm)	h_a	h_a=1m	2
4	Dedendum	h_f	h_f=1.25m	2.5

	(mm)			
5	Pressure angle (degree)	α	Degree	20
6	Tooth thickness (mm)	t	t=1.6m	3.2
7	Tooth height (mm)	h	$h=h_a+h_f$	4.5
8	Face width (mm)	w	w=5m	10
9	Root diameter (mm)	d_f	$d_f=d-2h_f$	43
10	Outside diameter (mm)	d_a	$d_a=d+2h_a$	52
11	Pitch circle diameter (mm)	d	d=mz	48
12	Base circle diameter (mm)	d_b	$d_b = d \cos \alpha$	45.12

7.3 NOISE MEASUREMENT

Spur gear pair is of materials GFRP, Steel and MMC. The noise is at speed of 50,100,150 and 200 rpm respectively, by changing motor speed. The noise is measured by sound meter.

Table 7.3 Noise level of GFRP gear pair

	Glass fibre reinforced polymer (GFRP)				
	Max. noise	**47.7**	**49.3**	**51.8**	**52.6**
		50 RPM	**100 RPM**	**150 RPM**	**200 RPM**
S.No.	**Frequency (Hz)**	**dBA**	**dBA**	**dBA**	**dBA**
1	20	39.5	38.6	40.8	44.7
2	25	45.2	42.8	39.8	51.8
3	31.5	41.2	40.6	42.5	50.6
4	40	44.5	43.8	43.6	48.9

5	50	43.6	46.5	44.8	49.5
6	63	44.8	44.3	42.7	50.7
7	80	46.3	48.6	46.8	48.6
8	100	43.5	41.3	45.9	53.2
9	125	45.6	42.7	42.3	47.8
10	160	40.2	39.8	42.6	49.8
11	200	46.7	40.6	47.8	47.3
12	250	45.2	42.8	48.6	43.9
13	315	42.4	43.5	47.5	42.1
14	400	43.5	44.6	46.8	44.3
15	500	42	39.5	45.8	45.1
16	630	39.1	47.8	44.3	41.7
17	800	41.7	44.3	46.8	43.8
18	1000	41.6	41.7	47.3	45.4
19	1250	41.2	43.3	49.2	52.6
20	1600	42.2	42.7	51.8	42.3
21	2000	45.8	41.6	50.6	42.7
22	2500	47.7	39.6	49.8	44.5
23	3150	45.6	49.3	50.8	42.4
24	4000	45.2	47.8	48.6	42.1
25	5000	40.6	48.8	47.3	39.5
26	6300	38.4	42.9	46.8	42.5
27	8000	36.4	41.6	48.2	43.5
28	10000	39.2	47.8	49.6	38.7

Table 7.4 Noise level of MMC gear pair

	MMC (Al-Sic , MMC)				
	Max. noise	**50.9**	**52.6**	**54.8**	**55.2**
		50 RPM	**100 RPM**	**150 RPM**	**200 RPM**
S.No.	**Frequency (Hz)**	**dBA**	**dBA**	**dBA**	**dBA**
1	20	34.5	39.8	40.5	40.7

2	25	36.5	36.5	41.2	41.1
3	31.5	36.8	35.4	49.7	49.9
4	40	48.6	37.6	44.8	43.2
5	50	39.5	38.6	49.2	49.7
6	63	40.5	40.6	47.3	47.3
7	80	42.6	41.2	44.1	44.2
8	100	43.8	41.8	50	50.2
9	125	44.5	42.6	44.9	43
10	160	42.8	43.9	46.6	44.9
11	200	43.8	48.6	44.5	44.4
12	250	40.6	47.8	45.9	41.6
13	315	42.5	46.1	43.1	38.7
14	400	46.8	45.2	46	42
15	500	49.8	49.8	44.3	38.2
16	630	45.7	49.1	40.7	35.8
17	800	44.6	50.1	43	38
18	1000	43.8	50.6	41.6	38
19	1250	44.1	51.8	41.5	38.3
20	1600	48.6	51.1	42.5	55.2
21	2000	49.5	52.6	44.6	40.5
22	2500	50.1	52.2	49	44.3
23	3150	50.2	50.9	45.6	39.7
24	4000	50.9	49.8	43.3	37.7
25	5000	49.8	47.6	54.8	33.5
26	6300	48.7	48.1	32.4	27.6
27	8000	47.3	49.6	32.7	27.1
28	10000	46.1	44.3	34.5	29

The rpm is measured by non-contact type tachometer to tune rpm from 50, 100, 150, and 200. Noise measurement is done with help of hand held noise meter cum analyzer model 2250, Bruel and Kjaor make.

Table 7.5 Noise level of steel gear pair

	Steel				
	Max. noise	**52.3**	**54.2**	**56.7**	**58.2**
		50 RPM	**100 RPM**	**150 RPM**	**200 RPM**
S.No	**Frequency (Hz)**	**dBA**	**dBA**	**dBA**	**dBA**
1	20	29.8	32.6	40.9	40.4
2	25	31.5	35.8	46.3	43.3
3	31.5	32.9	36.9	51.2	49.3
4	40	35.4	36.6	45	44
5	50	39.5	37.5	50	50.7
6	63	32.4	29.6	47	46.8
7	80	36.5	40.5	44.2	44.3
8	100	38.6	41.8	50.9	50.3
9	125	39.5	42.6	42.8	42.4
10	160	41.5	44.5	44.7	44.1
11	200	43.5	43.2	44.1	42.9
12	250	42.6	40.8	41.3	40.6
13	315	44.8	45.6	39.1	38.4
14	400	45.6	48.8	40.2	39.1
15	500	46.8	49.3	39.3	37.8
16	630	47.3	50.4	37.3	35.5
17	800	42.8	51.8	40.6	37.3
18	1000	46.7	52.6	56.7	37.2
19	1250	44.8	54.2	41	37.9
20	1600	49.8	53.8	40.6	37.9
21	2000	50.6	52.9	42.4	58.2
22	2500	52.3	53.9	47.4	44.3
23	3150	50.9	46.8	44	40.3
24	4000	51.8	44.6	45.1	42.1
25	5000	49.6	48.7	37.4	34.5
26	6300	48.2	49.8	32.8	29.3
27	8000	47.2	48.7	32.5	28.5
28	10000	46.1	48.1	34.4	30.1

Figure 7.1 Noise measurement setup

The noise measuring setup is shown in figure 7.1.Analyzer is held at a distance of 500 mm from the gear setup. The noise level varies from the frequency of 20 Hz to 10000 Hz. The ear is very sensitive to sound between the frequency ranges of 500 Hz to 6000 Hz.

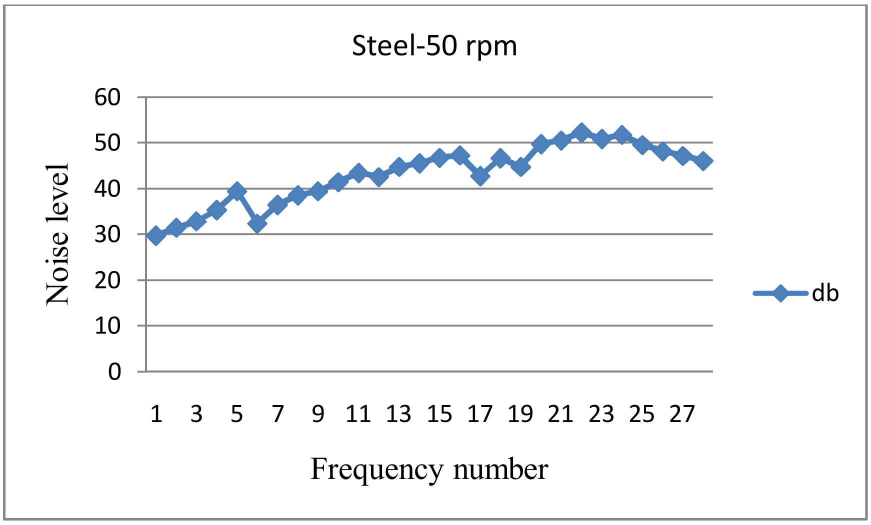

Figure 7.2 Trend analysis of steel gear pair at 50 rpm

Figure 7.2 shows trend analysis of steel gear pair at 50 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz. At 20 Hz noise is 29.8 dBA goes on increasing upto 50 Hz and drops to 32.5 dBA at 63 Hz and then goes on increasing maximum value is 51.8 dBA at 4000 Hz.

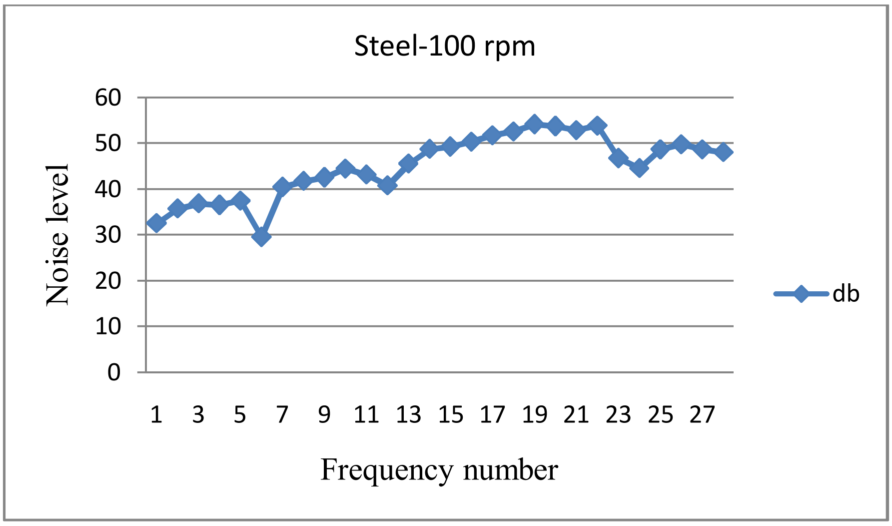

Figure 7.3 Analysis of steel gear pair at 100 rpm

Figure 7.3 shows trend analysis of steel gear pair at 100 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz. At 20 Hz noise is 32.6 dBA goes on increasing upto 50 Hz and drops to 29.6 dBA at 63 Hz and then goes on increasing,maximum value is 53.9 dBA at 2500 Hz.

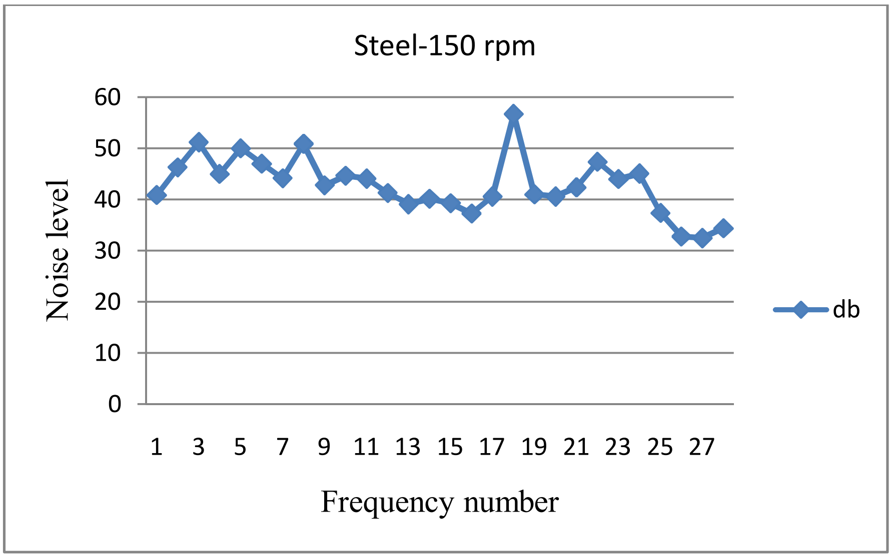

Figure 7.4 Analysis of steel gear pair at 150 rpm

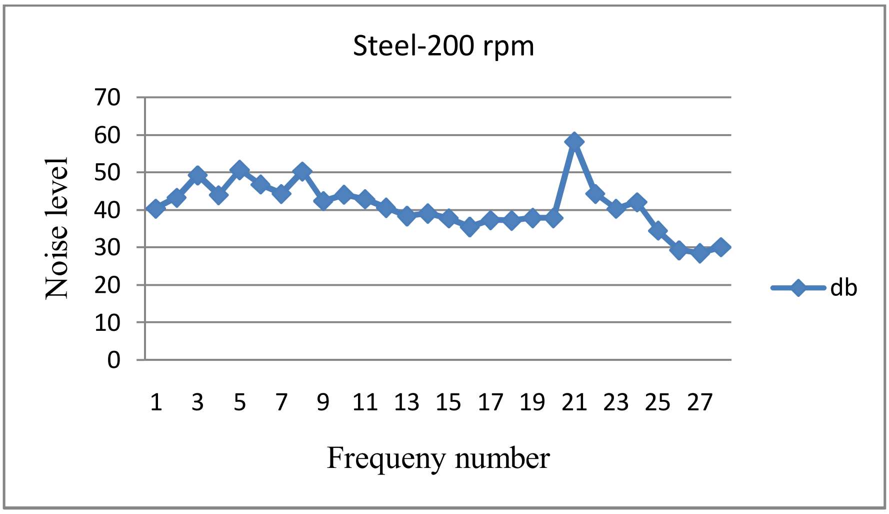

Figure 7.5 Analysis of steel gear pair at 200 rpm

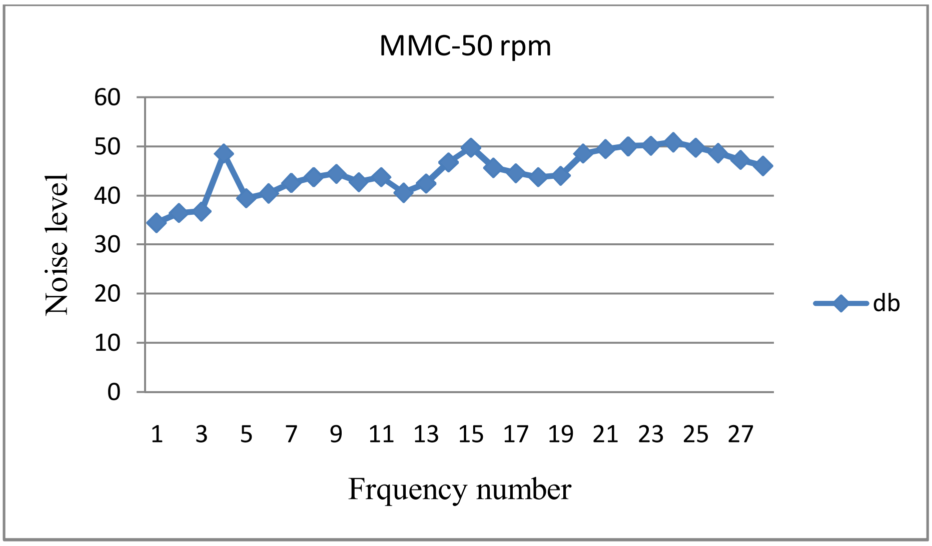

Figure 7.6 Analysis of MMC gear pair at 50 rpm

Figure 7.4 shows trend analysis of steel gear pair at 150 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz. At 20 Hz noise is 40.9 dBA goes on increasing upto 31.5 Hz to the value of 51.2 dBA and drops to 45 dBA at 40 Hz and then goes on increasing to the maximum value of 56.7 dBA at 1000 Hz.

Figure 7.5 shows trend analysis of steel gear pair at 200 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz. At 20 Hz noise is 40.4 dBA goes on increasing upto 31.5 Hz to the value of 49.3 dBA and drops to 44 dBA at 40 Hz and then goes on increasing to the maximum value is 58.2 dBA at 2000 Hz

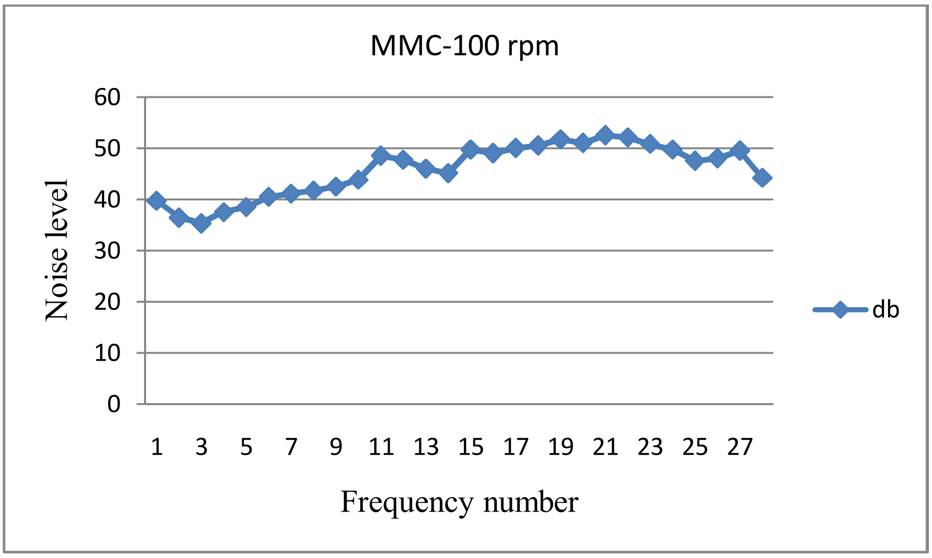

Figure 7.7 Trend analysis of MMC gear pair at 100 rpm

Figure 7.6 shows trend analysis of MMC gear pair at 50 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz. At 20 Hz noise is 34.5 dBA goes on increasing upto 40 Hz to the value of 48.6 dBA and drops to 39.5 dBA at 50 Hz and then goes on increasing to the maximum value is 50.9 dBA at 4000 Hz.

Figure 7.7 shows trend analysis of MMC gear pair at 100 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz. At 20 Hz noise is 39.8 dBA goes on increasing upto 25 Hz to the value of 36.5 dBA and drops to 35.4 dBA at 31.5 Hz and then goes on increasing to the maximum value is 52.6 dBA at 2000 Hz.

Figure 7.8 shows trend analysis of MMC gear pair at 150 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz.

At 20 Hz noise is 40.5 dBA goes on increasing upto 31.5 Hz to the value of 49.7 dBA and drops to 44.8 dBA at 40 Hz and then goes on increasing to the maximum value is 54.8 dBA at 5000 Hz.

Figure 7.10 shows trend analysis of GFRP gear pair at 50 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz. At 20 Hz noise is 39.5 dBA goes on increasing upto 25 Hz to the value of 45.2 dBA and drops to 41.2 dBA at 31.5 Hz and then goes on increasing to the maximum value is 47.7 dBA at 2500 Hz.

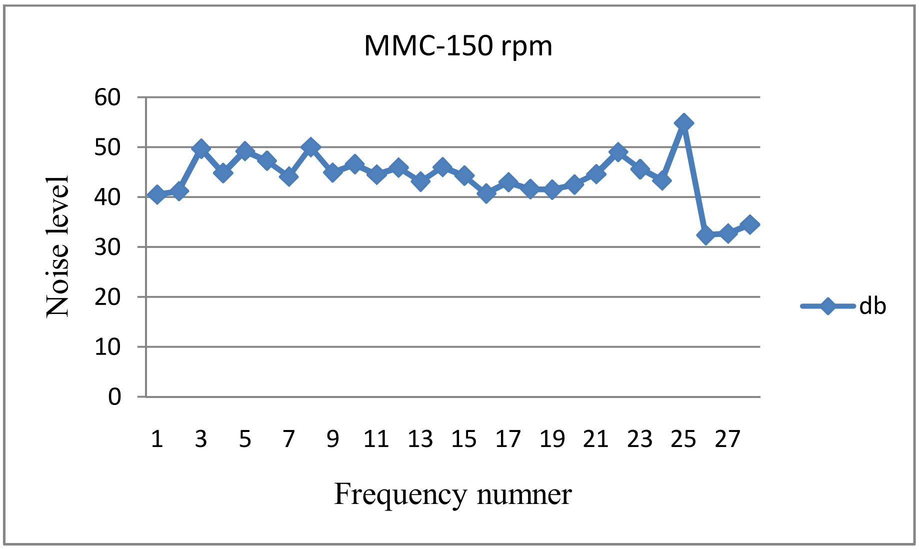

Figure 7.8 Trend analysis of MMC gear pair at 150 rpm

Figure 7.9 shows trend analysis of MMC gear pair at 200 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz. At 20 Hz noise is 40.7 dBA goes on increasing upto 31.5 Hz to the value of 49.9 dBA and drops to 43.2 dBA at 40 Hz and then goes on increasing to the maximum value is 55.2 dBA at 1600 Hz.Figure 7.11 shows trend analysis of GFRP gear pair at 100 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz.

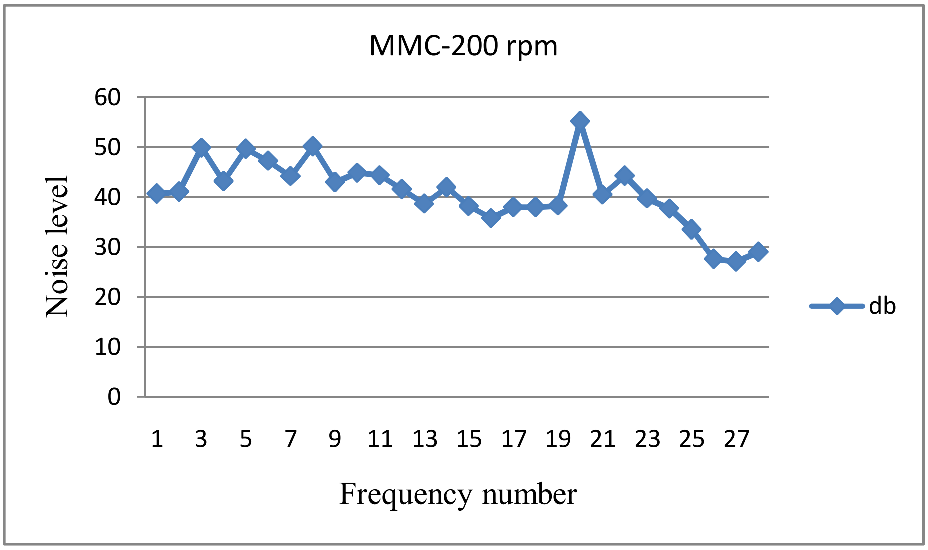

Figure 7.9 Trend analysis of MMC gear pair at 200 rpm

At 20 Hz noise is 38.6 dBA goes on increasing upto 25 Hz to the value of 42.8 dBA and drops to 40.6 dBA at 31.5 Hz and then goes on increasing to the maximum value is 48.8 dBA at 5000 Hz.Figure 7.12 shows trend analysis of GFRP gear pair at 150 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz.

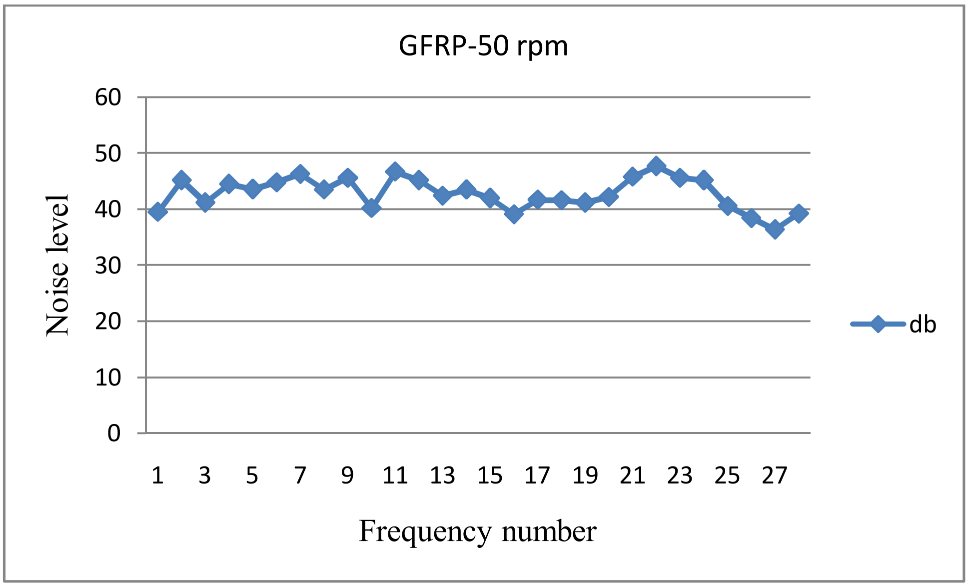

Figure 7.10 Trend analysis of GFRP gear pair at 50 rpm

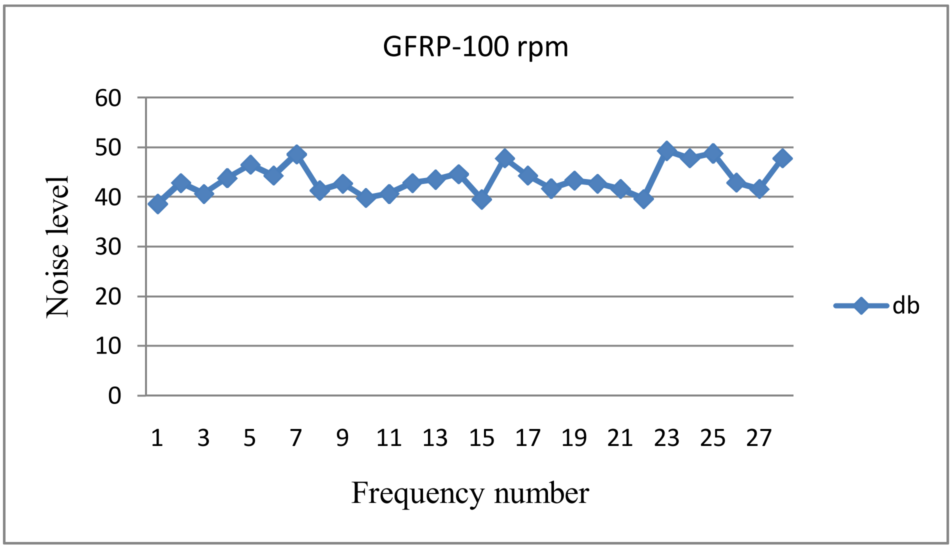

Figure 7.11 Trend analysis of GFRP gear pair at 100 rpm

At 20 Hz noise is 40.8 dBA goes on increasing upto 50 Hz to the value of 44.8 dBA and drops to 42.7 dBA at 63 Hz and then goes on increasing to the maximum value is 50.8 dBA at 3150 Hz.Figure 7.13 shows trend analysis of GFRP gear pair at 200 rpm with respect to variation of frequency ranging from 20 Hz to 10000 Hz.At 20 Hz noise is 44.7 dBA goes on increasing upto 25 Hz to the value of 51.8 dBA and drops to 50.6 dBA at 31.5 Hz and then goes on increasing to the maximum value is 52.6 dBA at 1250 Hz.

The human ear is more sensitive to sound in the frequency range 1 kHz to 4 kHz than to sound at very low or high frequencies. The knowledge about human ear is important in acoustic design and sound measurement.

To compensate, sound meters are normally fitted with filters adapting the measured sound response to the human sense of sound. Using the dBA filter, the sound level meter is less sensitive to very high and very low frequencies. Measurements made with this scale are expressed as dBA. Noise is measured at four different rpm in controlled conditions and results are given in Table 7.6.

It is obvious that with the increase of speed of spur gears for various materials, the noise in dBA increases for all the three materials. Sound level meter measured least noise in GFRP, slightly more in MMC and highest in steel. It is established that use of GFRP can limit noise in power transmission through gears.

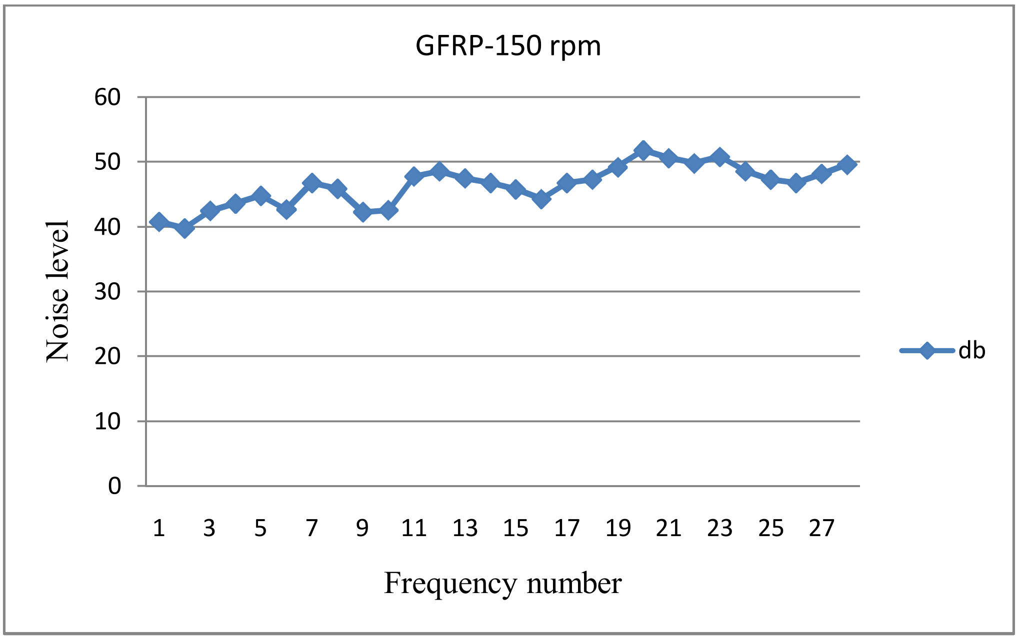

Figure 7.12 Trend analysis of GFRP gear pair at 150 rpm

The comparison of noise at 50 RPM for GFRP, MMC and steel is given in Figure 7.14.Which shows that GFRP goes upto the noise level of 47.7 dB, MMC goes upto 50.9 and Steel gears goes upto 52.3 dB.

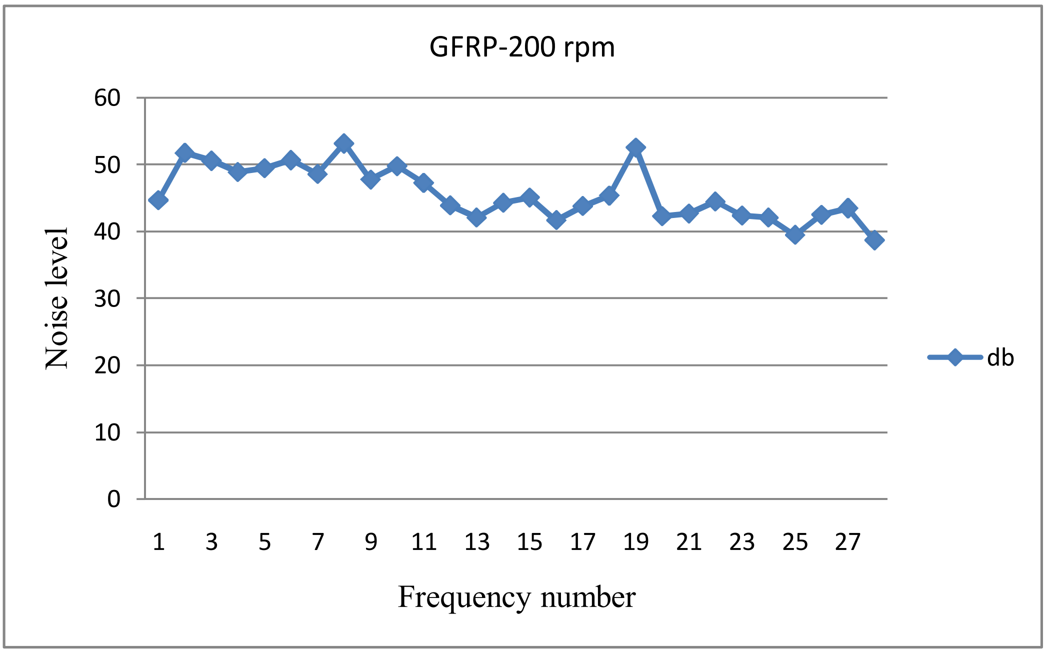

Figure 7.13 Trend analysis of GFRP gear pair at 200 rpm

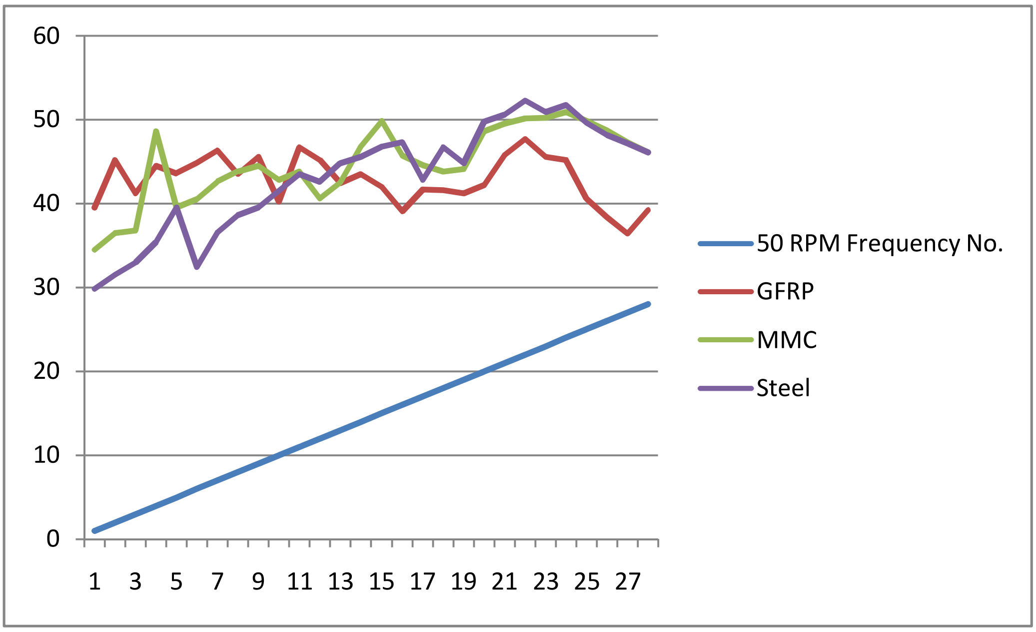

Figure 7.14 Comparison of noise at 50 RPM for GFRP, MMC and Steel

The comparison of noise at 100 RPM for GFRP, MMC and steel is given in Figure 7.15.Which shows that GFRP goes upto the noise level of 49.3 dB, MMC goes upto 52.6 and Steel gears goes upto 54.2 dB.

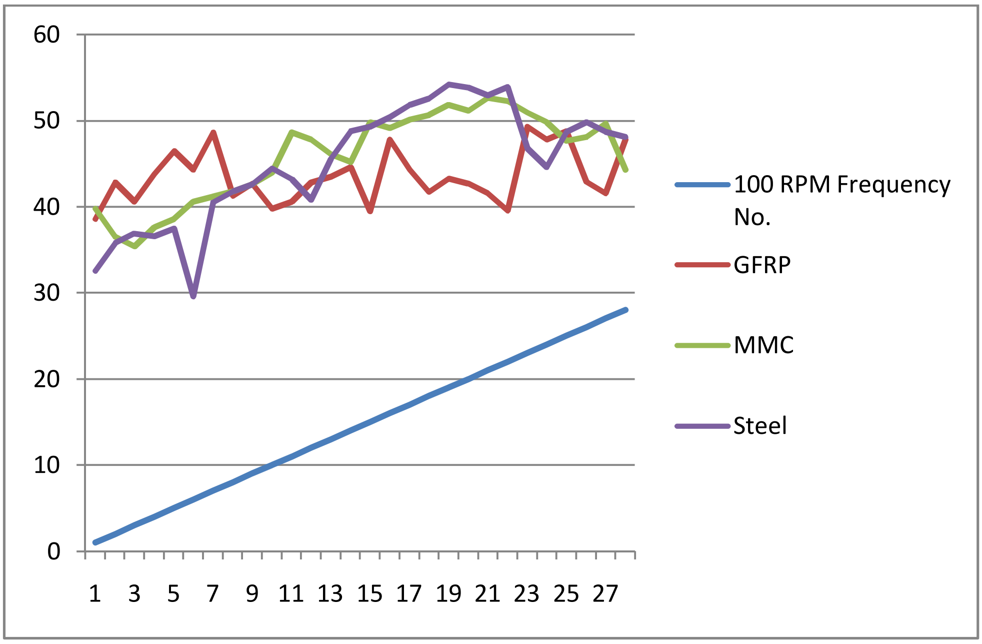

Figure 7.15 Comparison of noise at 100 RPM for GFRP, MMC and Steel

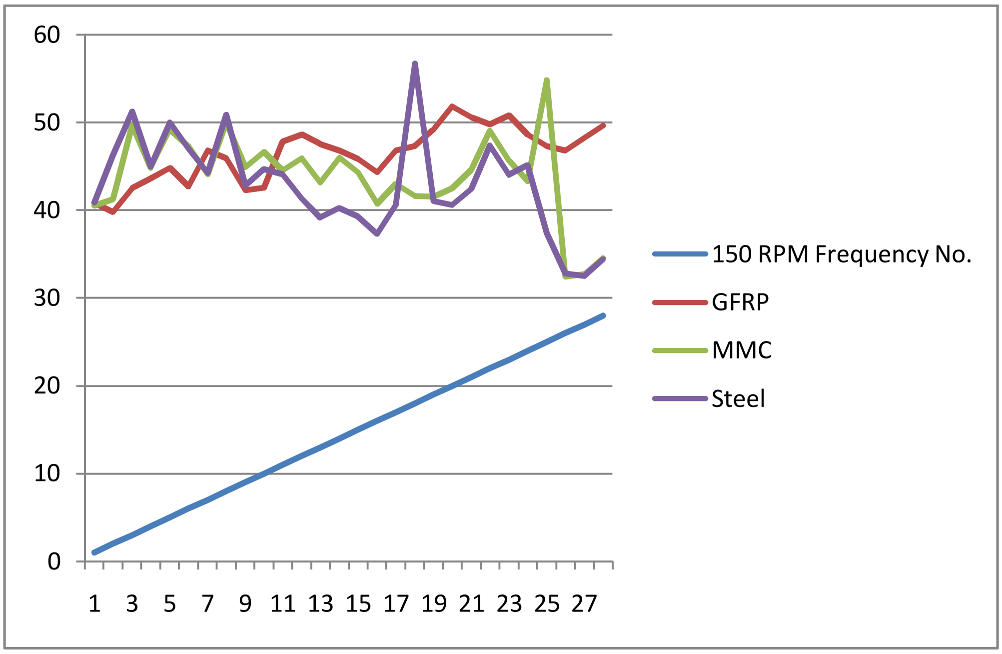

Figure 7.16 Comparison of noise at 150 RPM for GFRP, MMC and Steel

The comparison of noise at 150 RPM for GFRP, MMC and steel is given in Figure 7.16.Which shows that GFRP goes upto the noise level of 51.8 dB, MMC goes upto 54.8 and Steel gears goes upto 56.7 dB.The comparison of noise at 200 RPM for GFRP, MMC and steel is given in Figure 7.17.Which shows that GFRP goes upto the noise level of 52.6 dB, MMC goes upto 55.2 and Steel gears goes upto 58.2 dB.

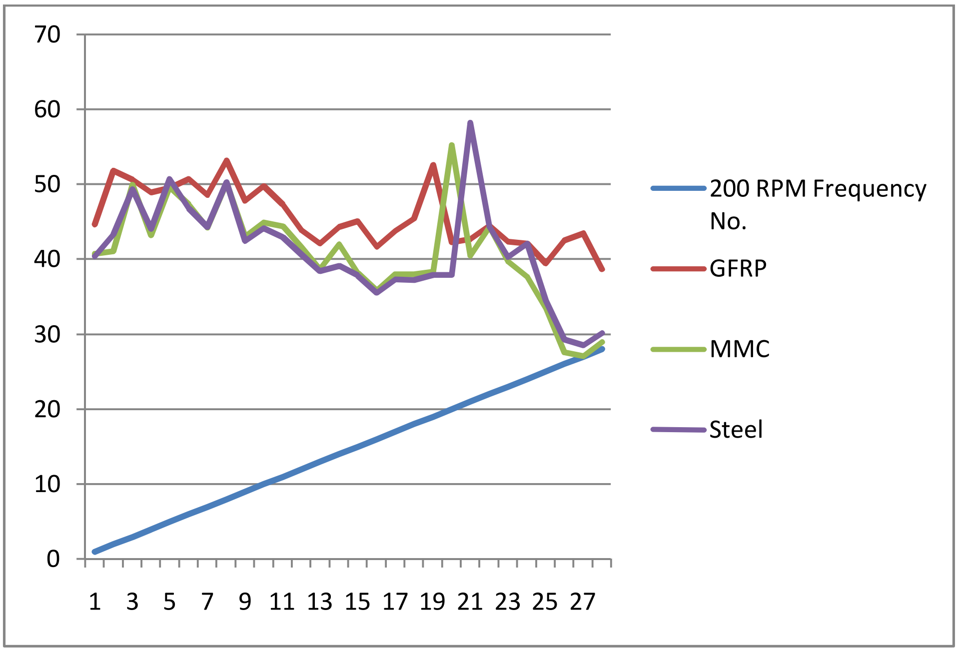

Figure 7.17 Comparison of noise at 200 RPM for GFRP, MMC and Steel

Table 7.6 Noise level at four speeds of gear pair

Material	**Gear Speed 50 rpm Noise in dBA**	**Gear Speed 100 rpm Noise in dBA**	**Gear Speed 150 rpm Noise in dBA**	**Gear Speed 200 rpm Noise in dBA**
GFRP	47.7	49.3	51.8	52.6
MMC	50.9	52.6	54.8	55.2
Steel	52.3	54.2	56.7	58.2

7.4 SHOT PEENING OF METAL MATRIX COMPOSITE GEAR

MMC spur gear is manufactured by stir casting process as mentioned in chapter 3. This gear is subjected to shot peening process to study its effect. Spur gear normally fails in three ways:-

1. Failure of tooth in bending at the fillet.
2. Wear of tooth surface by combined effect of rolling at pitch circle diameter.
3. Sliding at addendum, dedendum region.

Shot peening is the method in which residual compressive layer is imparted on the surface of gears. It is a cold working process to modify mechanical properties of metal gears and MMC. In these process steel and ceramic shots of different shapes depending upon the characteristics requirement, bombarded on the surface of gear to create plastic deformation. Power transmission gears are characterized by tensile stress generated during machining, which accelerates the fatigue failure. After shotpeening the tensile layer get replaced by the compressive layer resulting in increased life. These shots create dimples on the surface and retract back. The top layer of gear gets compressed and becomes hard due to the bombardment of steel shots. Residual stress gets develop on the surface. Shot peening has special advantage for gears for increasing hardness, removing micro cracks, cleaning surface etc.

Advantages of shotpeened gears are:-

(i) Increase in fatigue life.
(ii) Small dimples acts as cavity for lubricant storage.
(iii) Increase in hardness.
(iv) Removal of extra material.
(v) Increase in tensile strength

Shot material to be used for bombardment is steel, ceramic, glass etc. Components like gears, steel shots are used for high intensity peening. For low and medium intensity peening glass and ceramic shots are used.Almen test strip is used to measure the intensity of the shot. In testing strip is bombarded with shots and the curvature obtained is measured on the almen gauge.

Intensity on the gear surface depends upon distance from the shot nozzle, angle of nozzle, velocity of the shot.Surface area of the gear to be covered during the shot peening requires 100% coverage. Root fillet radius of the gear is the area which should be strong enough. It improves bending strength of the tooth. Involute surface after shot peening results in pitting and scoring resistant. Dimples which is generated after shot peening works like oil pocket for gear teeth in between sliding surfaces.

To maintain the quality of shotpeened surface specifications AMS2430 standards are followed.Residual compressive stress gets produced at surface of metal due to bombardment of steel shots of diameter 0.5 mm. As shown in Figure 7.14 the surface of MMC gear has small indentations of balls.

Figure 7.18 MMC gear after shot peening

7.5 SAND BLASTING OF GLASS FIBER REINFORCED POLYMER GEAR

GFRP gear could perform better when applied with lubricating coatings on the surface of tooth. Bonding strength between the coating and parent material should be strong enough to withstand over a period of cycles.

Figure 7.19 GFRP gear after sand blasting

In sand blasting the gear is put in an enclosed chamber and bombarded with sand particles to make the small indentations on the surface of gear. As shown in Figure 7.15 the GFRP gear is sand blasted. The indentation on the gear can be varied by changing the distance between sand blasting nozzle and work piece. Speed of sand particles, size of sand particles and time duration are three variables to control quality of gear. As shown in Figure 7.15 the surface of GFRP has small pores to hold the coating layers. It increases the bonding strength to sustain coated layer for a longer time.

7.6 HARDNESS OF STEEL, METAL MATRIX COMPOSITE AND GLASS FIBER REINFORCED POLYMER

Hardness of AISI 4140 steel, MMC and GFRP after shot peening process is given below:-

(i) AISI 4140 steel, HB – 197 (with shot peening, 210)
(ii) MMC HB – 62.5 (with shot peening, 71)
(iii)GFRP – not done

There is improvement in hardness due to shot peening process.

7.7 SUMMARY

In this chapter noise analysis of GFRP, steel and MMC gear is done at four different speeds. It is found that noise is least in GFRP followed by MMC and then steel. For a particular material as the speed increased from minimum to maximum the noise level increases. For gears high noise occurs at a particular frequency. It is found experimentally that the frequency at which noise is high vary from one speed to another and different for different materials. For low noise gear box and lower load requirements the GFRP is best suited. For moderate noise and medium load transmission capabilities, MMC is appropriate. For high transmission of load where high noise is tolerable steel gear box is suitable. Shot peening of the MMC gear improve the hardness of gear. It is useful for increasing life of gear in wear and fatigue. Sand blasting is done on the outer surface to produce small dimples. It is helpful in holding protective and lubricating coatings on gear top most surfaces. It reduces the friction between gear sliding surfaces.

CHAPTER 8

CONCLUSIONS AND SCOPE FOR FUTURE WORK

In this chapter, contribution of the present research work is discussed. Present research focus on enhancing the tolerances of GFRP gear by shaping process. This research tries to modify the surface finish of GFRP gear teeth through shaping. On the basis of present research work, its conclusions and limitations, the recommendations and scope for future work is presented in this chapter.

8.1 CONCLUSIONS

The present research work deal with the problem which is repeatedly faced in the production of gears. The conclusions of this work will go a long way in removing the obstacles and ensuring the noiseless and smooth surface gears.

The following section presents the major findings as follows:

- Optimum cutting condition to manufacture gear in terms of root diameter deviation, tooth thickness variation and surface roughness has been identified by Taguchi, Grey relational analysis, response surface methodology.
- This research work provides the optimum quality for GFRP gear which is 10-20 % light in weight, have lesser noise, reliable and cheaper in comparison to MMC, steel gears.
- Through Taguchi and GRA optimization of machining conditions has been done to settle minimum values of root diameter deviation, tooth thickness variation, surface roughness at 0.213 mm, 0.165 mm and 1 µm.
- Response surface methodology optimization technique using Box Behnken method reduced the surface roughness. The best predicted surface roughness found is 0.902 µm which is closed to experimental value of 0.82 µm.
- Impact of the cutting parameters on the surface roughness is found out through value of F ratio from the ANOVA.Cutting speed is having the highest value of 114.9 affecting the surface roughness to the highest extent, cutting fluid ratio is having the value of 86.66 influencing the surface roughness on second number and rotary feed is having the value of 12.43 influencing the surface

roughness on third number. All the three parameters are having the p-value equal to 0.000. It is less than 0.05 and hence they are significant.

- The optimum machining parameters are found as cutting fluid ratio 8%, cutting speed 180strokes/min and Rotary feed 0.17 mm/stroke. The significant parameters which affect the performance characteristics are at 97.61 % confidence level.
- The second order model has been developed to predict the surface roughness using response surface methodology based on cutting parameters. It is having R-square adjusted value of 95.76% which shows the correctness of the model if new terms will be added.
- Noise analysis of GFRP, steel and MMC has been done at four different speed. It has been found that noise is least in GFRP followed by MMC and then steel. For a particular material of the gear, as speed increased from minimum to maximum the noise level increases. It has been found that the frequency at which noise is maximum vary from one speed to another and different for different materials.
- Shot peening of the MMC gear improved the hardness of gear. It is useful for increasing life of gear in wear and fatigue.
- In the computer aided engineering analysis of MMC the effect of variation of root fillet radius on factor of safety has been studied by finite element analysis on Ansys workbench. It has been found that when root fillet radius varies from 0.1 to 0.5 mm the factor of safety improved from 1.26 to 2.05.

8.2 RESEARCH LIMITATIONS

Research limitations, based on the newly developed process in the field of gears shaping, can be described as:

(i) Testing of the gear is time consuming process but can give better results.

(ii) Involute profile is a complicated profile, if customized fillet radius is to be manufactured than separate cutting tools are required for each profile, which is a costly affair.

(iii) Strength of GFRP gear is lesser in comparison to metal gears so it is not suitable for higher loads.

8.3 SCOPE FOR FUTURE WORK

(i) The helical gear instead of spur gear can be designed and machined on gear shaper which has lesser noise than spur gear.

(ii) The hybrid gear having core of MMC and teeth of GFRP can be optimized through gear shaping process in three steps.

(iii) The present developed process can be used for different ratio of glass fibers in polymer composites and compared with one another for gear metrology and surface roughness.

(iv) The research can be extended to gear hobbing of GFRP to enhance the process performance.

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BRIEF PROFILE OF THE RESEARCH SCHOLAR

Atul Sharma completed his B.Tech. (Mechanical Engineering), M.Tech. (Mechanical Engineering) in first division from YMCA university of science and technology, Faridabad. He is the PhD research scholar under the esteemed guidance of Dr. M.L. Aggarwal, Professor in Department of Mechanical Engineering, J.C. Bose University of Science and Technology,YMCA, Faridabad and Dr. Lakhwinder Singh, Professor in Department of Mechanical Engineering, J.C. Bose University of Science and Technology,YMCA, Faridabad. Research scholar is having 21 years of industrial experience. Presently he is working as Head of Section in Machine Shop of J.C. Bose University of Science and Technology,YMCA, Faridabad.His research area of interest are manufacturing and materials.

1. List of Published Papers in International Journals (03)

S. No	Title of the paper along with volume, Issue No, year of Publication	Publisher	Impact factor	Refereed Or Non-Refereed	Whether you paid any money or not for publication	Remarks
1.	Experimental Investigation into the Effect of Noise and Damping using Composite Spur Gear, Materials Today,pp 2777-2782, 4(2017),doi.org/10.1016/j.matpr.2017.02 . 156. ISSN: 2214 – 7853.	Elsevier Ltd, U.K.	Not Mentioned	Refereed	No	Indexed in SCOPUS
2.	Optimization of cutting parameters for surface roughness of polyamide 66/33 glass fiber composite gear using response surface methodology, International Journal of Research in Advent Technology, pp 2074 – 2080, Volume 6, Issue 8, August 2018. E-ISSN: 2321 – 9637.	MG Aricent, India.	Not Mentioned	Refereed	No	U.G.C Approved Journal
3.	Effect of Fillet Radius on Aluminium Silicon Carbide Metal Matrix Composite Spur Gear, International Journal of Recent Advances in Mechanical Engineering, Volume 4, No. 2, pp 137-148,May 2015, DOI: 10.14810/ijmech.2015.4213, ISSN : 2200 - 5854	Wireilla Scientific, Australia.	Not Mentioned	Referred	No	

2. List of Accepted Papers (in Press) in International Journals (01)

S. No	Title of the paper along with volume, Issue No, year of Publication	Publisher	Impact factor	Refereed or Non-Refereed	Whether you paid any money or not for publication	Remarks
1.	Investigation of GFRP gear accuracy and Surface roughness using Taguchi and Grey Relational Analysis,2018, ISSN 1793-6896	Word Scientific Publishers, Singapore	Not Mentioned	Refereed	No	Indexed in ESCI, SCOPUS

3. List of Published Papers in International and National Conferences (02)

S. No	Title of the paper along with volume, Issue No, year of Publication	Publisher	Impact factor	Refereed Or Non-Refereed	Whether you paid any money or not for publication	Remarks
1.	An Investigation on the cutting parameters for shaper to reduce noise of spur gear, in Proceedings of National Conference on RSTTMI, pp 368 – 370, 2016.	Proc. Conf. at YMCAUST , Faridabad, Haryana	Not Mentioned	--	Conference Fee	--
2.	Noise Reduction Using Glass Fiber reinforced Polymer Gear, in Proceeding of National Conference on TAME, pp 200 – 202, 2017	Proc. Conf. at YMCAUST , Faridabad, Haryana	Not Mentioned	--	Conference Fee	--