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Parametric Modeling and Weight Analysis of Glass Filled Polyamide Composite Differential Gearbox

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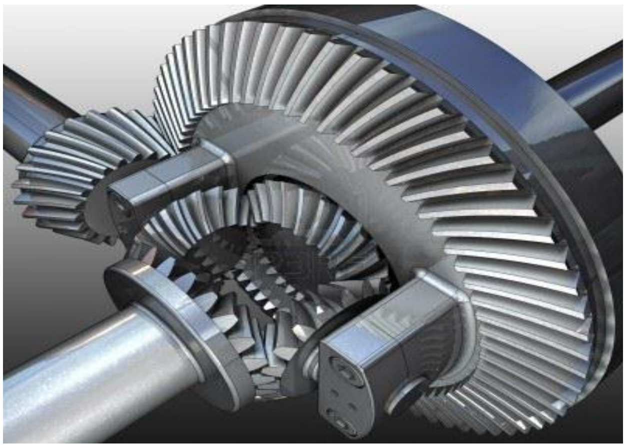
Abstract— **The main objective of this paper is to developed parametric model of differential Gearbox by using CATIA-V5. It is observed that Glass filled polyamide composite material is selected as best material for differential gearbox and is found to suitable under static loading conditions. Comparisons of Weight Analysis of Glass filled polyamide composite Differential with metallic materials Differential (Aluminum alloy, Alloy Steel and Cast Iron) and found to be lower for composite material.**

Index Terms— **Parametric Modeling, Differential Gearbox Design, Assembly and Weight Analysis.**

I. INTRODUCTION

The upcoming requirement of power saving and efficiency of mechanical parts during the past few years increased the use of composite materials. Moreover the use of composite materials have also increased due to their properties such as weight reduction property with enough strength , high specific stiffness, corrosion free, ability to produce complex shapes, high specific strength, high impact energy absorption and many more. Product development has changed from the traditional serial process of design, followed by prototype testing and manufacturing but to more on computer aids. CAE (Computer Aided Engineering) has greatly influenced the chain of processes between the initial design and the final realization of a product. CAE software helps in product designing, 3-D visualization, analysis, simulation and impacted a lot on time and cost saving to the industry.



A Gear box is one of the important mechanical components of transmission system used in variety of machines. Differential Gear box increases effective weight of vehicle which in turn directly affects the performance and efficiency of the vehicle. So there is a requirement to make light and effective gears. Therefore, in the present work composite materials are used to make light weight gears in order to perform such duty efficiently.

1.1 Background

The Differential Box transmits mechanical energy from a prime mover to an output device. It also changes the speed, direction or torque of mechanical energy. Differential gearbox is used when high speed, large power transmission where noise abatement is important. Some limitations in existing Differential gear box are as follows:

- It has poor weight to strength ratio so high power loss.
- Metallic parts lead to corrosion so need to properly shielded.
- More wear in between the gears so required proper lubrication.
- Due to heaviness of Differential gear box, it needs to be strongly mounted thus increasing more weight and decreasing fuel efficiency.
- Its cost is more due to increasing cost of metals.

Existing differential has poison's ratio, mass density and shear modulus is also low. Thus Differential gear box needs to be redesigned providing energy saving by weight reduction, providing internal damping, reducing lubrication requirements and have high tensile strength, elastic modulus, poison's ratio, mass density and shear modulus without increasing cost. Such a scope is provided by application of composite material providing substantial weight reduction in conformance with safety standards and also providing solution to other existing problems in current gears available.

2 LITERATURE REVIEW

In this paper, literature has been critically reviewed involving various studies carried out by various researchers related to the field of parametric modelling and weight analysis of Differential gearbox. Differential gearbox is an important part of the automobile i.e. used for transmitting different speeds, while for most vehicles supplying equal torque to each of them. **F. K. Choy et al. [1]**, provided a comparison and benchmarking of experimental results obtained from a damaged gear transmission system with those generated from a numerical model. Specific conclusions for this study can be summarized as follows: 1. A study of the dynamic changes in a gear transmission system due to (a) no gear tooth damage, (b) single gear tooth damage, (c) two consecutive gear teeth damage, and (d) three consecutive gear teeth damage is successfully conducted. 2. The vibration signature analysis using a joint time-frequency procedure, the Wigner-Ville distribution (WVD), seems to be quite effective in identifying single and multiple teeth damage in a gear transmission. **Riccardo Morselli et al. [2]**, showed a detailed dynamic model of an electronically controlled steering differential has been proposed. To obtain faster and still reliable simulations, reduced dynamic models have been obtained by a proper state-space transformation and simplification of the detailed model. The steering differential models allow the simulation of the dynamical behavior of the most common car differentials. The proposed reduced model has been used to compare the effects of four kinds of differentials on the vehicle dynamics. **Erwin V. Zaretsky et al. [3]**, developed two computational models to determine the fatigue life and reliability of a commercial turboprop gearbox are compared with each other and with field data. These models are (1) the Monte Carlo simulation of randomly selected lives of individual bearings and gears comprising the system and (2) the two-parameter Weibull distribution function for bearings and gears comprising the system using strict-series system reliability to combine the calculated individual component lives in the gearbox. The Monte Carlo simulation consisted of the virtual testing of 744,450 gearboxes. These results were compared with each other and with two sets of field data obtained from 64 gearboxes that were first-run to Removal for cause, refurbished, placed back in service, and second run until removal for cause. A series of equations was empirically developed from the Monte Carlo simulation to determine the statistical variation in predicted life and Weibull slope as a function of the number of gearboxes failed. **Cuneyt Fetvaci et al. [4]**, generated the simulation of conventional spur gear with asymmetric involutes teeth has been studied. The complete geometry of a rack-type cutter for spur gear with asymmetric involutes teeth production has been given. In addition to the given mathematical model for describing generating and generated surfaces, the mathematical model of the trochoidal envelope of the cutter tip has been derived. Computer programs have been developed to obtain computer graphs of generated tools and generated surfaces. Variations on the tooth form and effects of changing tool parameters on the produced tooth form can be investigated before it is manufactured. A numerical example using the finite element method is given to investigate the influence of tool parameters on generated gear tooth stresses. The results of calculations clarify that tooth root stress decreases remarkably by the use of a larger pressure angle in the back profile of the tooth. **Lei Wang et al. [5]**, researched the theory of hybrid-driving differential gear trains and carrying out experiment many times on the designed test-bench, finally, this article obtains two conclusions: (1)This paper designed a test-bench of hybrid-driving two degree of freedom differential gear trains, and its mechanical properties are reliable and stable, low noise, smooth running. Generally speaking, it is able to achieve the anticipated purpose. (2)This test-bench uses PLC component to enable system control more precise, easy operation, debugging easy, gathering the data accurately and conveniently. It provides a good experimental platform for the basic theory research in the future. **Isad Saric et al. [6]**, developed parts by using interactive modeling are modeled parameter. While geometric gear modeling in CATIA V5 system, we do not have to create shape directly, but, instead of that, we can put parameters integrated in geometric and/or dimensional constraints. We get resulted 3D solid gear model by characteristic parameters changing. In this way, designer can generate more alternative designing samples, concentrating his attention on design functional aspects, without consideration of details of elements of shape. Time used for designing is reduced for 50%, by parameter modelling application and focusing on preparation phase. Direct financial effects can be seen in reducing of production costs, and that is the result of increase production. In that way, better profit and price of products are lower. **C. Fetvaci [7]**, developed mathematical models of external and internal involutes spur gears according to the generation mechanism with a gear-type gear shaper. By applying the equations of the profile of the cutter, the principles of coordinate transformation, the theory of differential geometry, and the theory of gearing, the mathematical models of the tooth profile including the fillets, bottom lands, and working surfaces, have been given. To investigate the shape of the generated tooth root fillet surfaces, the mathematical model of trochoidal envelope of cutter tip has been derived. The cutter tip traces epitrochoidal curve in external tooth generation and hypotrochoidal curve in internal tooth generation. **B. Venkatesh et al. [8]**, obtained Von-Misses stress by theoretical and ANSYS software for Aluminum alloy, values obtained from ANSYS are less than that of the theoretical calculations. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions, which are safe and less than the other materials like steel. Aluminum alloy reduces the weight up to 5567% compared to the other materials. Aluminum is having unique property (i.e. corrosive resistance), good surface finishing, hence it permits excellent silent operation. Weight reduction is a very important criterion, in order to minimize the unbalanced forces setup in the marine gear system, there by improves the system performance. **Dong Yang et al. [9]**, through the combination of both experience and the traditional theory of gear modification, had developed the concept of isometric modification. By selecting the appropriate modification size and modification location, tooth deformation would be compensated and the stress distribution would be controlled in the central part of the tooth; the load concentration, agglutination, pitting of the gear could also be avoided effectively. According to the gear geometry theory and the normal meshing motion equation of gear pairs, changes of meshing points and angles were analyzed, and then, the effect of axial modification on gear pair‟ s meshing movement was discussed. The establishment of the relationship between angle changes and modification size provided not only the basis for calculation and the selection of the modification size, but also a reference for the detection of modification effect in the future work. Based on the 3D software Solid Works, a method of drawing spherical in volute was achieved, and the solid modeling accuracy of spur bevel gear was improved. After solid modeling, dynamic emulation analysis was operated by FEA software. The analytical results had shown that stress distribution was controlled by isometric modification and the additional load was reduced effectively. **C. Veeranjaneyulu et al. [10]**, showed that by observing the structural analysis results using Aluminum alloy the stress values are within the permissible stress value. So using Aluminum Alloy is safe for differential gear. When comparing the stress Values of the three materials for all speeds 2400rpm, 5000rpm and 6400 rpm, the values are less for Aluminum alloy than Alloy Steel and Cast Iron. By observing the frequency analysis, the vibrations are less for Aluminum Alloy than other two materials since its natural frequency is less. And also weight of the Aluminum alloy reduces almost 3 times when compared with Alloy Steel and Cast Iron since its density is very less. Thereby mechanical efficiency will be increased. By observing analysis results, Aluminum Alloy is best material for Differential. **Anoop Lega et al. [11]**, the main objective of the research was developed the composite material gear box using computer aided Engineering. The modeling of gears was done using parametric methodology; 3D family was generated by set of variables which controls other gear dimensions related gear design laws. The tool provides 3D models for a wide family of gears used as base for stress & deformation analysis using finite element method. Solid models of gears, shafts and housing were generated and assembled using CATIA software package. Product Design Specification sheet was developed for the gearbox and simultaneously material selection was carried out through detailed study and past performance of composite materials. Gearbox assembly is imported in Ansys software package and evaluated for equivalent (von-Misses) stress and equivalent (von-Misses) elastic strain for both composite material and existing metallic material. Comparative Results revealed the feasibility of composite material gearbox with approximately 60% weight saving and lower stresses then metallic gearbox with other composite material advantages.

3 SOLID MODELLING

Solid modeling consists of set of principles for mathematical and computer modeling of three-dimensional solid model. It refers to theories and computations that defines and manipulates representations of physical objects, their properties and the associated abstractions, and that support a variety of processes. Solid modeling of bevel and spur gears is done using parametric approach. Bevel gears for different dimensions can be generated by changing the variables (number of teeth, pressure angle, helix angle, tooth thickness, module). Required parameters that are used as variable for generating bevel gear and dependent parameters with relations are shown in table 1. In the reference model there are five bevel gears variable values for each gear as given in table2. Steps involved in the creation of parametric solid model of bevel gear are shown in Figure 2 while Figure 3 (a) - (e) shows the solid model models of gears.

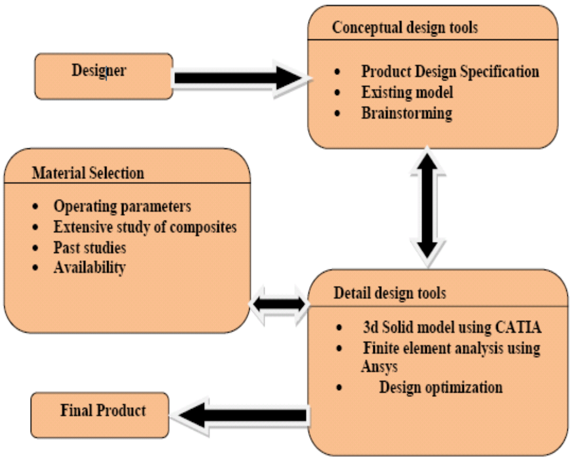


Figure 1 Link between various design activities

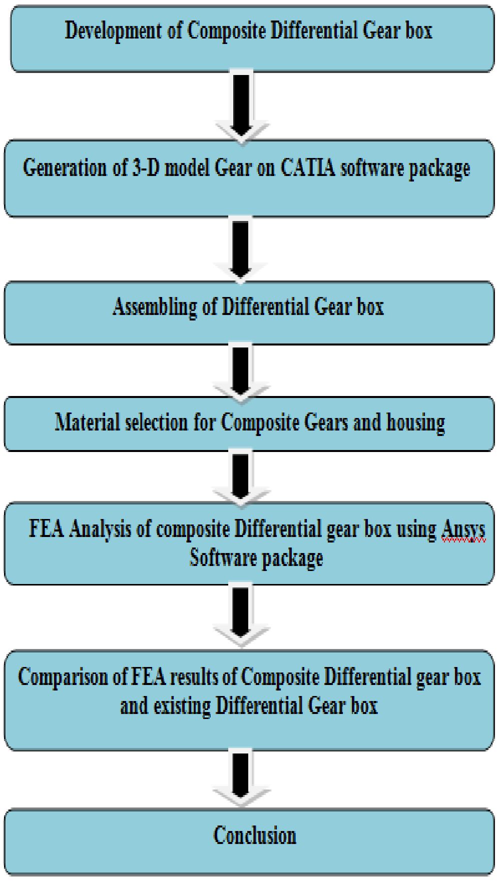


Figure 2 Steps involved in work flow.

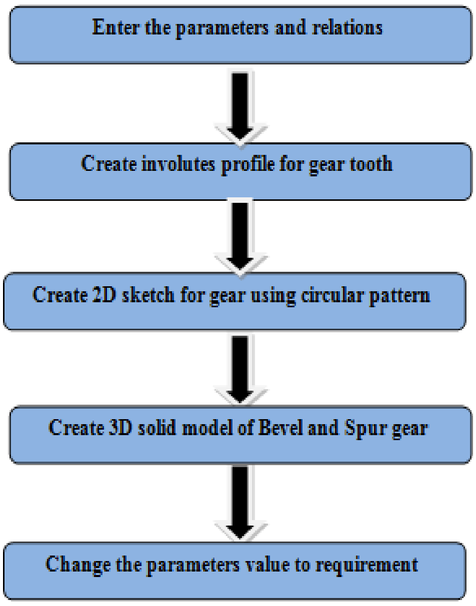


Figure 3 Steps involved in the creation of parametric solid model of bevel gear

Table 1 Variable values for five bevel gear Formulas for Spur and Bevel Gears

Sr. No.	Pressure angle (A) (degree)	Modulus (m) (degree)	No. of teeth (Z1) (integer)	No. of teeth (Z2) (integer)
Gear 1	20	2	20	12
Gear 2	20	2	25	25
Gear 3	20	2	12	20
Gear 4	20	2	48	25
Gear 5	20	2	12	20

Table 2 Product - Design Specification Sheet.

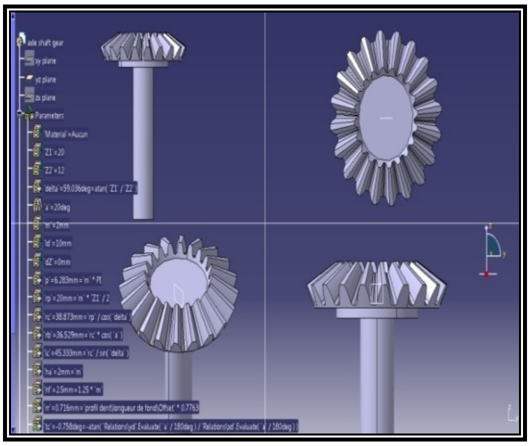
Product Design Specification of Composite material Gearbox	
Density	< 2710 Kg/m 3
Creep resistance	High
Fatigue strength	High
Corrosion resistance	High
Impact strength	High
Manufacturing method associated with material must be high volume production	
The component made from this material must be dimensionally stable and provides internal damping	
The material should have low friction coefficient	

Table 3 Material Properties of Gears

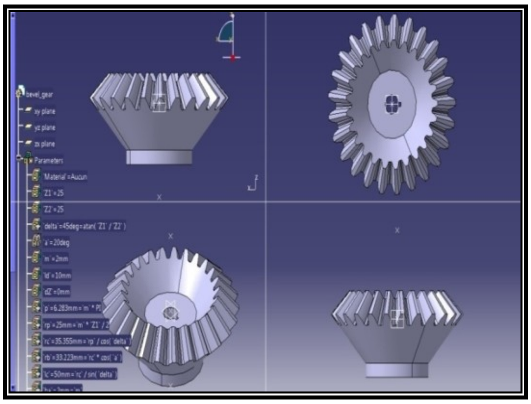
Final material for Composite Gear	
Material Type	Glass filled Polyamide
Material supplier	Dura form
Percentage of glass filling	20 % by volume
Tensile Modulus	5910 MPa
Tensile strength	38.1 MPa
Poisson's ratio	0.314
Flexural modulus	3300 MPa
Density	840 kg/m^3
moisture Absorption	0.30%
creep resistance	Good
corrosion resistance	Good
Chemical Resistance	Alkalis, hydrocarbons , fuels and solvents

Table 4 Parameters and Relations are used for generating bevel gear of Differential Gear box

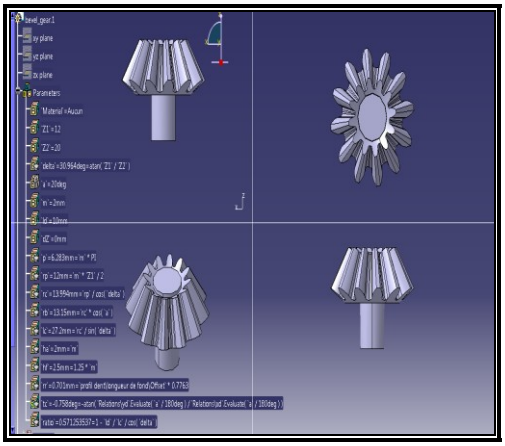
Spur Gear	Bevel Gear
Z	Z_1, Z_2
m	m
$a = 20\deg.$	$a = 20\deg.$
$r = (Zm)/2$	$r = (Z_1 m)/2$
$rb = rc\cos(a)$	$rb = rc\cos(a)$
$rf = r - 1.2m$	-
$ra = r + m$	-
$rr = 0.38m$	$rr = 0.38m$
$ha = m$	$ha = m$
$hf = 1.2m$	$hf = 1.2m$
$xd = rb(\cos(t\Pi) + \sin(t\Pi)t\Pi)$	$xd = rb(\cos(t\Pi) + \sin(t\Pi)t\Pi)$
$yd = rb(\sin(t\Pi) + \cos(t\Pi)t\Pi)$	$yd = rb(\sin(t\Pi) - \cos(t\Pi)t\Pi)$
$0 <= r <= 1$	$0 <= r <= 1$
	$delta = a\tan(Z_1 / Z_2)$
	$rc = r/\cos(delta)$
	$lc = rc/\sin(delta)$
	$tc = -a\tan\left(\begin{matrix}\mathrm{Re}\,lations \setminus ydEvaluate(a/180\deg.)/ \\ \mathrm{Re}\,lations \setminus xdEvaluate(a/180\deg.)\end{matrix}\right)$
	$B = 0.3rc$
	$Ratio = 1 - b/lc/\cos(delta)$
	$dz = 0mm$



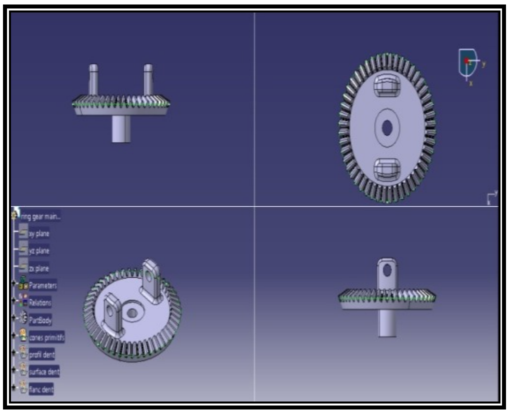
1. Axle Side Shaft Gear



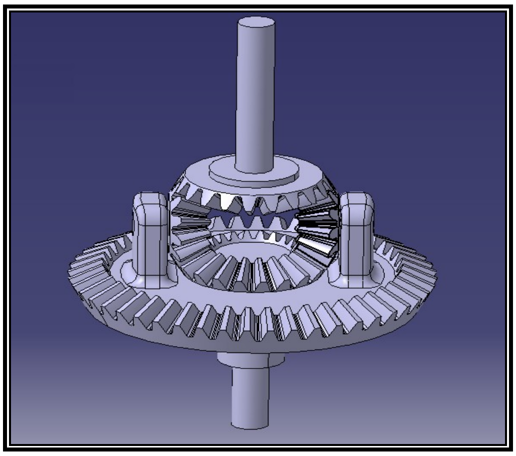
2Bevel Gear



3 Inner Gear



4 Ring Main Gear



5 Main Assembly

Figure 4 Solid model models of gears.

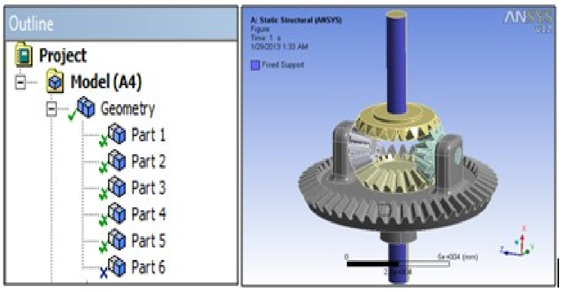


Figure 5 Differential gear box.

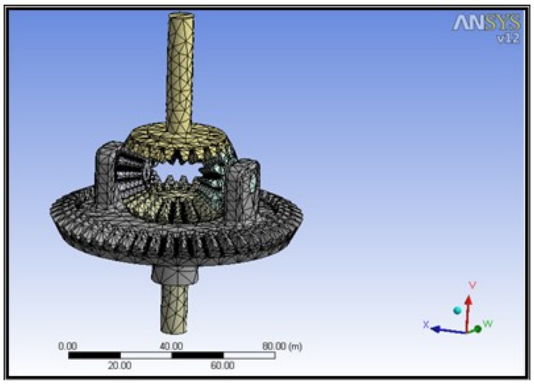


Figure 6 The meshed Differential gearbox.

4 MATERIAL SELECTIONS

Engineering data imparts the material properties. Composite materials made from two or more constituent materials with significantly different physical or chemical properties. These constituent materials combined to produce a material with characteristics different from the individual components. The composite material selection for gearbox is done using if –then approach, using product design specification sheet Table 2. Glass filled polyamide in particulate form is used for differential gear box(bevel and spur gears)having better tensile strength (38.1 Mpa), recyclability, low density (840 Kg/m 3), high creep resistance, fatigue strength, high impact strength, low Von-Misses Stress, less friction and low cost. Table 4 gives the properties of glass filled polyamide and E-glass/Epoxy.

Nickel Chrome Steel

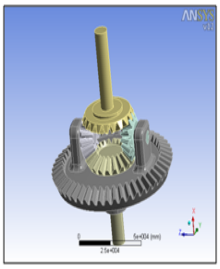
Model Reference	**Properties**
	**Name:** Nickel Chrome Steel **Model Type:** Linear Elastic Isotropic **Default Failure Criterion:** Max Von Misses Stress **Yield Strength:** 1.72339x10^8 N/m^2 **Tensile Strength:** 4.13613 x10^8 N/m^2 **Elastic Modulus:** 2x10^{11} N/m^2 **Poisson's Ratio:** 0.28 **Mass Density:** 7800 Kg/m^3 **Shear Modulus:** 7.7x10^{10} N/m^2 **Thermal Expansion Coefficient:** 1.1x10^5 /Kelvin

Figure 6.1 Properties of Nickel chrome steel Differential gear box.

Aluminum Alloy

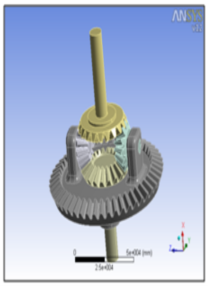
Model Reference	**Properties**
	**Name:** al_alloy7475-t761 **Model Type:** Linear Elastic Isotropic **Default Failure Criterion:** Max Von Misses Stress **Yield Strength:** 1.65 x10^8 N/m^2 **Tensile Strength:** 3 x10^7 N/m^2 **Elastic Modulus:** 7 x10^{10} N/m^2 **Poisson's Ratio:** 0.33 **Mass Density:** 2600 Kg/m^3 **Shear Modulus:** 3.189 x10^8 N/m^2

Figure 6.2 Properties of Aluminum Alloy Differential gear box.

Cast Iron

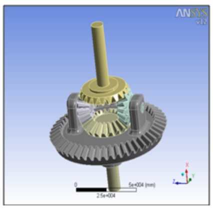
Model Reference	**Properties**
	**Name:** Malleable Cast Iron **Model Type:** Linear Elastic Isotropic **Default Failure Criterion:** Max Von Misses Stress **Yield Strength:** 2.75742 x10^8 N/m^2 **Tensile Strength:** 4.13613 x10^8 N/m^2 **Elastic Modulus:** 1.9 x10^{11} N/m^2 **Poisson's Ratio:** 0.27 **Shear Modulus:** 8.6 x10^{10} N/m^2 **Thermal Expansion Coefficient:** 1.2 x10^5 /Kelvin

Figure 6.3 Properties of Cast Iron Differential gear box.

Glass Filled Polyamide

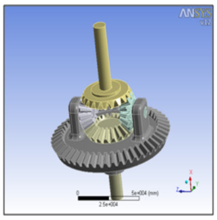
Model Reference	**Properties**
	**Name:** Glass Filled Polyamide **Model Type:** Linear Elastic Isotropic **Default Failure Criterion:** Max Von Misses Stress **Yield Strength:** 5910 Mpa **Tensile Strength:** 38.1 Mpa **Poisson's Ratio:** 0.314 **Mass Density:** 840 Kg/m^3 **Shear Modulus:** 3300 Mpa

Figure 6.4 Properties of Glass Filled Polyamide Differential gear box.

5 RESULTS

Table 5 Comparison chart for net weight saving.

S.NO.	Component	Net Weight With Ni Chrome Steel (Kg)	Net Weight With Al (Kg)	Net Weight With Cast Iron (Kg)	Net Weight with Composite Material (Kg)	Quantity	Weight Saving
1	Gear 1	37.23	32.45	41.45	8.29	1	28.753
2	Gear 2	58.567	50.89	64.37	12.14	1	45.802
3	Gear 3	29.13	23.62	34.14	6.82	1	22.143
4	Gear 4	190.25	167.24	210.07	42.01	1	147.176
5	Gear 5	58.567	50.89	64.37	12.87	1	45.072
Total weight		**373.744**	**325.09**	**414.4**	**82.13**		**288.948**

Analysis is the application of analytical techniques for checking the utility and feasibility of any design under predetermined specifications. The current work evaluates 3D modeled concepts for composite material Differential Gearbox using Finite Element Analysis (FEA). In this work FEA is for developing Solid Parametric Models by using some parameters i.e (number of teeth, pressure angle, helix angle, tooth thickness, module) in CATIA-V5 with reference of Table 1 and Table 4 and Weight Analysis of Differential Gear box for Different materials (Aluminum alloy, Alloy Steel, Cast Iron and Glass filled Polyamide) under static conditions. Figure 4 shows Differential gearbox. Figure 5 shows the meshed Differential gearbox. Figure 6.1 to Figure 6.4 show properties of different materials used for Differential gear box. In the present work, Table 5 shows the comparison chart for weight saving using composite material in place of metallic material. The net weight saving of approximately 60% of existing weight is found.

6 CONCLUSIONS

The present work relates to composite material differential gear box as an effective alternative to existing metallic differential gearbox. Computer aided engineering is found to be useful tool for various design stages. Reference model of Differential gear box is selected and CATIA is used to develop various parametric models of reference Model. Glass filled polyamide composite material is used for Differential Gearbox in comparison with traditional materials (Aluminum alloy, Alloy Steel, Cast Iron).

The following conclusion of the present works is discussed below:-

1. Weight of Glass filled polyamide Composite Material of Differential gearbox is reduced by 60% as compare to the traditional materials (Aluminum alloy, Alloy Steel, Cast Iron).
2. Light and easy to handle.

By observing these results, Glass Filled Polyamide composite material is selected as a best material for Differential gear box which in turn increases the overall mechanical efficiency of the system.

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