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Design and Analysis of Herringbone Gear using Polymers for using off Road Vehicles

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Abstract— A herringbone gear is a type of gear that is used to transmit power between two parallel shafts. It is referred as a herringbone gear because its teeth are arranged in a V-shape that resembles the bones of a fish. Even though Herringbone gears are commonly used in heavy-duty machinery, such as turbines, compressors, and industrial gearboxes, they have found their usage in not only home appliances but also in small consumer items such RC vehicles as part of planetary gear motor. Herringbone gears used for such small-scale application are commonly made from thermoplastics like acetal homopolymer. Stress cracking commonly occurs in acetal-based polymer and are but in general acetal copolymer exhibits better resistance than acetal homopolymer. Analysis will be done to find a better substitute to acetal homopolymer in acetal copolymer.

Index terms: Acetal copolymer, Eigenvalue buckling, Acetal homopolymer, Herringbone gear, Transient analysis

I. INTRODUCTION

The term "herringbone" refers to a pattern of parallel, slanted lines that resemble the bones of a fish, such as a herring. The pattern is created by arranging rectangular shapes or lines in a way that alternates direction, forming a zigzag shape. It has two sets of helical teeth that are opposite in direction, but arranged side by side, cancelling out the axial thrust that would be created by a single helical gear. This makes herringbone gears ideal for high-speed and high-load applications where smooth and efficient power transmission is required.

They are similar to helical gears, but they have teeth that are arranged in two opposite directions, which cancel out the axial thrust that is produced by helical gears. This makes herringbone gears ideal for high-speed and high-load applications, where smooth and efficient power transmission is required. In a planetary gear motor, the herringbone gear is typically used as the stationary internal gear, with the planet gears orbiting around it. The gear's unique double helical tooth profile helps to reduce vibration and noise, making it ideal for use in planetary gear motors that require smooth and efficient power transmission. The use of herringbone gears can also increase the overall efficiency of the gear motor, as the opposing helixes cancel out axial thrust and minimize power loss due to friction. Planetary gear motors are commonly used in a wide range of applications, including robotics, automation, and transportation, where high torque and compact size are important factors. The use of herringbone gears in planetary gear motors helps to ensure reliable and efficient operation of these systems. The most commonly used materials for making herringbone gears in planetary gear motor of remote-controlled vehicles is acetal homopolymer.

Compared the physical and mathematical results conducted in accordance with the properties of radio-controlled cars with the results that come out from the simulation (motion analysis) in CAD software. As mentioned, these results will depend on the physical properties of radio-controlled cars (e.g. mass, torque of stepper motors, the radius of wheels, angle of slope of wheels) and the properties of the environment, (e.g. plan surface, angle of slope plan). In order to have successful result which leads to proper operation (desired movement) of a radiocontrolled car we must choose the appropriate electrical component (e.g. Arduino, stepper drivers, stepper motors and batteries) and the suitable electrical component for a safe movement (e.g. camera, led)[1]. Finite element analysis of a wheel hub, which is an important and most loaded component in an automobile. Wheel hub need to carry different loads ranging from static weight of the vehicle, cornering force, wheel torque etc. For better working of a wheel hub it has to take all these loads without failure. Safety of a vehicle depends on the wheel hub. A high-quality wheel hub allows vehicles to carry heavy loads, function in extreme weather conditions, and run smoothly on rough roads. The thesis deals with linear static analysis of a wheel hub with different materials such as Delrin 500P, Carbon Reinforced Derlin, Glass Reinforced Derlin. This methodology is to predict the maximum stress areas and the maximum displacement in the part under consideration. The second objective is to predict the best material for this particular application by comparing the results after conducting linear static analysis[2]. Made the use of plastic and polymer composite gears is increasing because of their low cost, lightweight and quiet operation compared to metal. gears. Plastic gears find application in printers, cameras, timers, counters, etc. Four different combinations of materials for pinion and gear were selected in the present work, and a comparative study was done to investigate mechanical and thermal properties analytically. Analytical results werevalidated using SOLIDWORKS and ANSYS. Design 1 and Design 2 were found out to be preferable designs. Maximum principal and maximum shear stress generated were minimum for Design 1 (pinion of Polycarbonate and gear of Acetal. copolymer). Simultaneously, the deformation and temperature rise were minimum for Design 2 (pinion of Nylon 66 and gear of Acetal. copolymer)[3]. Static, Modal and Fatigue Analysis has been carried out on herringbone gears using ANSYS tool. Alloy Steel, GRP and Carbon fiber materials have been analysed and studied for comparison. The selection of better material for herringbone gear is determined out of this analysis. This Paper is the result of the analysis carried out by using ANSYS 14.5 on a 3D model of Herringbone gear which was generated using Solid works tool. The results are then compared with the help of graphs[4]. Described the dynamic characteristic and fatigue life of the gear meshing. Use the ANSYS to deal with the problem of motion errors which are the result of the wear and the curve caused by the rough surface of the gear generated by the low machining accuracy in the process. And through the analysis, the value and the changing trend of the equivalent stress, fatigue life, and fatigue sensitivity with different friction coefficients can be known. Then it provides an important theoretical basis to strengthen the strength and stability, reduce the deformation of the gear, and improve fatigue life[5]. Analyses the transmission efficiency of the herringbone gear by using the theory of nonNewtonian fluid line contact electrohydrodynamic lubrication. Firstly, the oil film pressure and thickness of the contact area are obtained, then the friction coefficient distribution and transmission efficiency in the herringbone gear mesh area are obtained. Finally, the influence of various parameters on the transmission efficiency is analysed[6]. Performed an extensive investigation of polymer gear (acetal. and nylon) friction and wear behaviour. First, a unique test method for polymer gear wear was described in brief and later used in the extensive investigation of acetal. and nylon gear wear. Initial tests were performed using acetal. pinions with acetal. gears, and nylon pinions with nylon gears, with further investigation carried out using dissimilar polymer gears. In this case the driver and driven effects on the gear wear behaviour was also considered when dissimilar materials were used. For acetal. against acetal. gears, it was found that the acetal. gear wear rate increased dramatically when the load reached a critical value for a specific geometry and the gear surface showed slow wear, with a low specific wear rate if the gear was loaded below this critical value. It was found that the surface temperature was the dominant factor influencing the wear rate and an initial relationship between gear surface temperature and gear load capacity has been established and further developed. Experimental investigation on nylon gears was also carried out and different failures have been found compared to acetal. gears, such as gear root and pitch fractures. The most interesting observation from the experimental work is the significant difference in wear behaviour when running acteal against nylon gears, especially the low wear rate when acetal. is used as the driver gear[7]. Provided a comprehensive overview of the dynamics and vibrations of herringbone gears. It covers the theoretical aspects of gear design, the causes and effects of gear vibrations, and various methods for analysing and mitigating gear vibrations[8]. In this book a comprehensive review of herringbone gears, covering topics such as gear geometry, design considerations, manufacturing methods, and analysis techniques. It also includes case studies and examples of practical applications of herringbone gears[9]. Provided a review of the theoretical and experimental investigation of herringbone gear efficiency. The research covered topics such as gear geometry, tooth contact analysis, and power losses due to gear meshing. It also includes experimental results for herringbone gears under different operating conditions[10]. To compare and justify the claim which acetal polymer is better, dynamic analysis will be performed as it is used to study the behavior of a structure or system under dynamic loading conditions, such as vibrations, impact, and time-varying loads and to understand how a structure or system will behave when subjected to these types of dynamic loads. Dynamic analysis is of different types and one of them which we will be using is transient analysis is used to analyze and predict the response of a structure or system to time-dependent inputs such as forces, displacements, or temperature changes. The purpose of transient analysis is to study the dynamic behavior of a system or structure under specific time-dependent loading conditions and to predict the system's response over time. The torque which the gear can withstand is supposed to be higher than the torque of the motor. As the motor taken into consideration for this project is from the works of Ardit J. Murati [1], the motor in their project can deliver a maximum torque of 0.123 Nm.

Despite the increasing popularity of polymer-based gears there is a limited understanding of herringbone gears used in consumer products especially with regards to acetal copolymers.

The focus will be on establishing a comparison between acetal homopolymer namely Delrin 500P and acetal copolymer namely Celcon and Tecaform AH on the basis of torque capacity of the gears with their respective materials.

II. DESIGNING OF GEAR

Table 1: Gear standards

Variable	Description	Value	Units
A1	No. of teeth	18	-
T	Torque	1	Nm
Ɵ	Helix angle	20	Degree
Φ	Pressure angle	20	Degree
b	Face width	32	mm

D	Outer Diameter	10.84	mm
d	Inner Diameter	9.2	mm

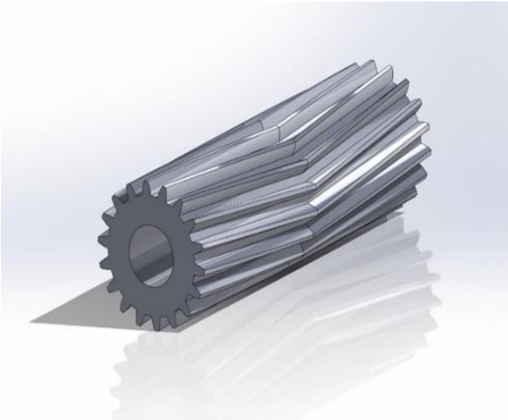

Figure 1 Model of Herringbone gear designed in Solidworks

III .MATERIALS

Acetal homopolymer, also known as polyoxymethylene (POM), is a thermoplastic material that is characterized by its high stiffness, strength, and dimensional stability. Acetal homopolymer is a crystalline thermoplastic that is derived from formaldehyde. which has a high melting point of around 175-180°C. It has high mechanical strength and stiffness, making it ideal for use in applications where strength and rigidity are important. It has a low coefficient of friction, which makes it ideal for use in bearings and other components where low friction is important. It has excellent dimensional stability, which means that it maintains its shape and size even when subjected to changes in temperature or humidity. It has good resistance to chemicals, including solvents and fuels. It is a machinable material that can be easily shaped and cut using standard machining tools. It is commonly used in the automotive, aerospace, and consumer goods industries for applications such as gears, bearings, electrical components, and medical devices. It has good resistance to abrasion and wear, making it suitable for use in applications where components are subjected to repeated friction and wear.

Acetal copolymer is a copolymer of acetal., meaning it contains both acetaldehyde and formaldehyde monomers in its chemical structure.It has good mechanical properties, including high strength, stiffness, and toughness, similar to acetal homopolymer. It has a low coefficient of friction,similar to acetal. homopolymer.It has good chemical resistance to a wide range of solvents, fuels, and other chemicals, similar to acetal.homopolymer.For the analysis, Delrin will be used, which is a brand name for an acetal homopolymer developed by the company DuPont. It is a type of polyoxymethylene (POM) that is known for its high strength, stiffness, and toughness, as well as its low coefficient of friction and excellent dimensional stability.Delrin is often used in applications that require high mechanical performance, such as gears, bearings, bushings, and other precision parts. It is also commonly used in the automotive, aerospace, and consumer goods industries.Celcon is a brand name for a family of acetal. copolymers produced by Celanese Corporation. Celcon is a high-performance engineering thermoplastic that has a unique combination of properties, including high strength, stiffness, and dimensional stability, as well as excellent resistance to chemicals and wear.Tecaform is a brand name for a type of acetal. copolymer plastic material. It is also sometimes referred to as POM-C or polyoxymethylene copolymer. Tecaform is a thermoplastic material that has excellent mechanical properties, such as high stiffness, low friction, and good wear resistance. It is also resistant to chemicals, moisture, and high temperatures. Tecaform is commonly used in a variety of applications, such as gears, bearings, conveyor parts, and medical devices. It is available in different grades with varying properties, such as improved creep resistance, enhanced dimensional stability, or enhanced wear resistance, to suit specific application requirements. There are several types of Tecaform available in the market, each with its own unique set of properties and characteristics.

IV METHODOLOGY

A cad model of herringbone gear is designed in a software called Solidworks. All the analysis are performed using Ansys workbench. The analysis has been done on the gear with three different Acetal. Once the part file had been transferred to Ansys, we choose the respective polymers from the “Engineering Data” toolbox. Once the polymer has been chosen, the constraints are applied on the model. Performing Eigen Buckling on the model until it fails under the application of a load due to instability caused by compression which leads to its failure. The eigen buckling value will be calculated, which is the lowest critical buckling load factor and the corresponding the eigen buckling will give us the maximum moment that the gears with the respective materials.

First, the geometry of the structure is modelled in Solidworks then the file is transferred to Ansys where the material properties are selected, boundary conditions are set and loads are applied. Next, the model is meshed, and appropriate element types and sizes are selected. Next step is to define the buckling analysis settings in ANSYS. This includes specifying the number of eigenvalues to be solved, the convergence criteria, and the type of solver to be used. After defining the buckling analysis settings, the eigenvalue buckling analysis is solved using ANSYS. The solver calculates the lowest critical buckling load factor and the corresponding mode shape of the structure. Finally, the results are post-processed and analysed to determine the stability of the structure. If the critical buckling load factor is less than the applied load, then the structure is considered to be unstable and prone to buckling. Eigen buckling will provide the moment for each gear with their respective materials, for that a finite element model of the gear is to be created and the appropriate loads and boundary conditions are applied. the moment of the gear can be calculated using the following equation:

$$M = P \times L / 4 \quad (1)$$

where M is the moment, P is the applied load, and L is the length of the gear. The value of P can be determined from the critical buckling load factor and the strength of the material used to make the gear. Finally, the results are post-processed and analyzed to determine the stability of the structure. Transient analysis in ANSYS is a simulation technique used to analyze the behavior of a structure or system over time in response to varying loads or conditions. Here are the steps involved in performing a transient analysis in ANSYS:

The geometry of the gear is defined, including material properties, boundary conditions, and initial conditions. Next, the model is meshed, and appropriate element types and sizes are selected. The next step is to define the transient analysis settings in ANSYS. This includes specifying the time step size, the total simulation time, the convergence criteria, and the type of solver to be used. After defining the transient analysis settings, the simulation is run in ANSYS. The solver calculates the response of the structure or system at each time step, based on the applied loads and boundary conditions.

The results are post-processed and analyzed to determine the behavior of the structure or system over time. This includes analysing stress, strain, displacement, and other relevant parameters at each time step. The results can be visualized and compared to the initial conditions and design requirements to determine if the structure or system is performing as expected. If necessary, the simulation can be refined or modified to improve the accuracy of the results or to evaluate different designoptions.

V. EXPERIMENT AND OBSERVATION

Table 2: Torque analysis for different materials

Torque	Delrin 500P	Celcon	Tecaform AH
(In Nm)	0.191	0.198	0.196

From the graph 2, Celcon has the most maximum shear stress compared to the others, which indicates that it has a higher material failure and damage due to shear loading.

If the maximum shear stress in a component exceeds the material's shear strength, it can result in deformation, cracking, or even fracture. Hence, making it a favorable material.

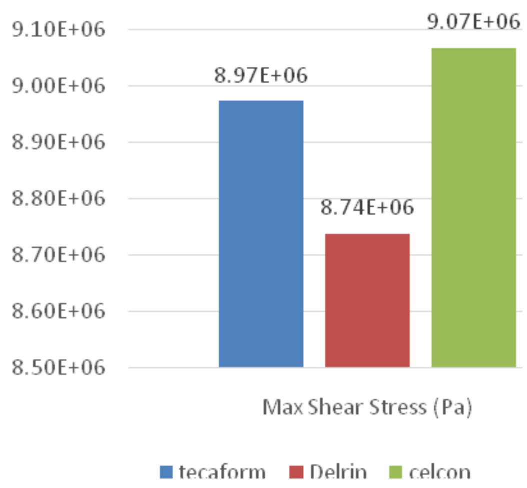

Figure 2: Graph showing Maximum Shear stress for different materials.

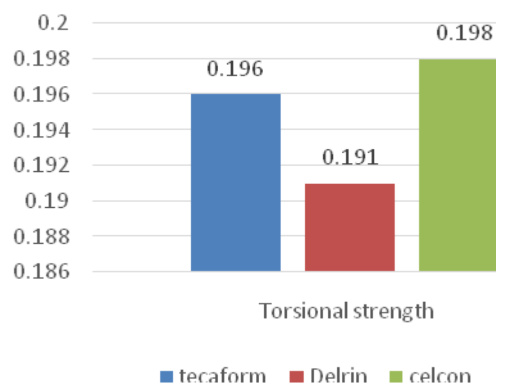

Figure 3: Graph showing torsional strength for different materials

From the above table it can be inferred that Celcon can withstand the maximum torque out of the three. The value of torque for Celcon is also higher than the torque of the motor taken into consideration thereby showing it will be suitable for the purpose.

VI . CALCULATION

The max torque that each gear of respective material can sustain can be found out using the formula

$$\tau = T * r * J \quad (2)$$

τ = Maximum shear stress

r = radius of gear T=Torque applied to gear

J=Polar moment of inertia of gear depending on the growth of gear

Since we are already with a solid circular gear, the polar moment of inertia is calculated as follows:

$$J = \frac{\pi *}{2} (D4 - d4)(3)$$

J = Polar moment of inertia

D = It is the outside diameter of gear = 10.8mm d = It is the diameter of the gear = 9.2mm

The results after applying the above formulas are as follows:

Table 3: Numerical analysis for different materials

From the above table it can be inferred that Celcon can withstand the maximum torque out of the three. The value of torque for Celcon is also higher than the torque of the motor taken into consideration thereby showing it will be suitable for the purpose.

Torque	Delrin 500P	Celcon	Tecaform AH
(In Nm)	0.191	0.198	0.196

VII. CONCLUSION

The different analysis that we performed on acetal. homopolymer namely Delrin 500P and acetal. copolymer namely Tecaform AH and CelconM90 present us with following conclusion.

The maximum shear stress and the equivalent stress are obtained from the transient analysis performed in ANSYS. In terms of maximum shear stress Celcon outperforms Tecaform AH (another acetal. copolymer) and is 3.75% better than Delrin 500P. In terms of equivalent stress, the pattern remains the same as Celcon outperforms Tecaform AH and is 3.97% better than Delrin 500P. In terms of Total deformation, the pattern repeats as Celcon outperforms Tecaform AH and is 3.58%cbteer than Delrin 500P.

Based on the results obtained from the analysis, it is recommended that the herringbone gear present inside the planetary gear motor used in a Remote-Controlled vehicle should be made from acetal copolymer (like Celcon) as compared to Delrin 500P. It can be concluded from the analysis that acetal co-polymer has performed better in terms of durability than acetal homopolymer, Delrin 500P**.**

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