A Review on a Straight Bevel Gear Made from Composite

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Abstract

The purpose of this work is to present a clear fundamental thought for designing and investigating straight bevel gear made of composite material. Composite materials have the advantage of being light, producing low noises, and extra loading capacities. Due to these properties, it is highly preferable over conventional materials. A comparison between different types of material used in a gear structure will be shown. The outcome shows that a new form of cheap material may be useful for designing a new type of lighter and stiffer gear, designed for robotic arm applications or any power transmission application.

Keywords: orthotropic materials, matrix composite, gear, torque

1. Introduction

Metals and alloys cannot forever fulfill the demand that is continuously created and increasing in today's market and technological advances. In order to emulate and supplement metals and alloys, combining existing materials will allow us to meet the ever demanding performance that is required for numerous applications. Recent advances in material processing technology have propelled composite materials to the forefront of material technological development. Due to its most prominent advantage such as high specific strength, high specific modulus, and special electrical properties, composite materials have attracted considerable attention of the engineering community, and are touted as potential substitutes for metal, such as in athletic equipment, automotive parts, aircraft and aerospace structural parts, transportation, oil installations and nuclear industries. Specifically, a number of composite transmission gears can be found in many different locations, for example, gear pumps, watches, devices, and washing machines. This is due to the fact that composites have good properties such as excellent corrosion resistance, high strength to weight ratio, high impact resistance and design flexibility. These properties make parts manufactured from composite materials high-quality, durable and cost-effective products (Mallick, 2007, Deborah, 2010, Autar, 2006, Valery et al., 2007, Denial et al., 2003). Although at this point it is also worth noting that although composite materials are able to withstand high impact resistance extremely well, there is often poor tolerance to accidental low velocity impacts which could limit their use in certain industrial applications. The types of damage which can occur are sometimes very difficult to detect visually and yet can also seriously affect the structural integrity of the materials. Composite are flexible in terms of modifications, fatigue resistance and its ability to absorb impact energy, making them very attractive to current industrial needs. The literature on isotropic metallic gears of both experimental and theoretical studies is massive, however, the author has managed to locate a few references regarding gears made from composite materials. In a general sense, the word composite means constituted of two or more different parts. In practice, the term composite material or composite is used in a more restrictive sense, as a material constituted by the assemblage of two or more materials of different natures, with complementary properties leading to a material which has better properties than the properties of the composite components considered separately (Ezhil & Paul, 2015).

During the last century, there have been major developments in the technology of power transmission by gears. In general, the materials used are mild steel and other conventional materials to construct the gear structure. However, these materials require extensive lubrication, which is quite costly, the lack of which will produce noise and vibration, which will in turn induce gear failure. These failures, and how to solve them using

composites will be discussed in next section. Composite materials are an area of research that plays a key role by reviewing the mesh stiffness of orthotropic material gears. It is capable of rebuilding the macro structures of materials in order to create new mechanical properties with the combination of low noise, lightweight, high strength and low usage of lubricants. As a result, it can be useful in power transmission applications. The metallic gear is heavy, and cannot be used without using a proper lubrication system. Moreover, plastic gears are lighter, has low loading capability, and weaker impact loading. Hence, composite gears are desired or even necessary in order to meet industrial requirements. This is a part of orthotropic material that can solve their entire gear problem without sacrificing strength, because they are lighter materials, making them essential for many industrial applications. The authors will attempt to understand the direction of potential stress and deformation variation for a straight bevel gear made from composite epoxies material (Peter, 2005; Sufyan et al., 2007, Haidar et al., 2015).

2. Effectiveness of Orthotropic Materials

The failure of metallic gears and other conventional materials can be caused by breakage and surface failure; however, composite materials are capable of circumventing these failures modes. Failures due to breakage are classified into three modes; the first mode involves a sudden breakage occurring at the root due to impact loading of the gearing. Composite materials address this problem by reinforcing the gear tooth with strong fibers, the combination of which will create materials with more load potential. The second failure mode due to breakage is fatigue at the tooth root due to constant repeated loading, and by utilizing composite materials; the stiffness of the gear tooth is increased and performs on par with another tooth body. And finally, the tooth corner breakage failure mode is mostly due to the uneven distribution of loads from axis misalignment, which is mostly caused by tooth alignment errors. This problem can be solved by die-casting the gear body using composite material in order to avoid manufacturing (generation) the gear tooth profile by rack cutters.

Wear and pitting on gear surfaces is another common type of failure. Pitting is caused by heavy contact pressure and the effect of lubrication. This failure can be avoided by making the tooth profiles smoother by casting them from composite material. Using composites make the surface of the gear tooth harder and stiffer, and the rigidity (higher yielding point) of composite material makes the teeth contact of the meshing gear Hartezian contact work with less lubricant. Improper material combination, poor surface finish and insufficient lubrication may cause wear failure (adhesive and abrasive). However, the hardness of composite material reduces the wear in gear teeth. Therefore, composite material is able to solve the entire gear problem, and create new fields of research of new types of material needed or required, without sacrificing strength. This will lead to extensive study in this field, and the formation of new macrostructures with excellent load ability, strength, lighter weight, less noise, less usage of oil and more wear resistance, by carefully selecting the type of matrix and reinforcement and studying the types of the arrangement that will address the gear tooth shape problem (Mohammed et al., 2007, Rongxian et al., 2010, Min et al., 2011).

3. Composite Gear Categories

Generally, any gear made from two or more materials with different properties and boundaries is considered a composite gear. This is further clarified below:

3.1 Metal Matrix Composite (MMC) Gear

Materials consisting of metal alloys reinforced with continuous fibres, particulates or whiskers are classified as MMC. The reinforced alloys by these constituents produce superior and unique physical and mechanical characteristics, which makes MMC suitable for a variety for applications. Its use is especially widespread in engineering due to its high strength, high power transmission, and medium weight, however, MMC are relatively more costly than polymers or ceramics. Generally, the reinforcement is done to tailor the specific applications. An example is the addition of SiC fibres, where it improves elastic stiffness and strength of metals, while reducing electrical conductivity. Ganesan and Vijayarangan (1993) conducted an investigation and compared the performance of a spur gear made of MMC materials to that made of conventional steel materials, and analyzed its static behavior in three dimensions using finite element analysis. They concluded that the behavior and performance of both MMC material gears and the mild steel gear are quite similar. The safety factor for the metal matrix composite showed the lowest values compared to other materials. Cedergren (2003) and his team demonstrate a method using a gear wheel to determine the porosity distribution within a complex powder compacted 3D structures using a dynamic 3D dilatant finite strain finite element program. The analysis showed that the porosity distribution in the powder compacted gears is dependent on the number of the gear teeth, thickness of the inner ring, the pressure angle, and is an excessive influence in the values of the porosity, which will induce small changes in its geometrical parameters. They stated that the minimum porosity distribution in

the metal matrix composite gear is 3%, and this is achieved by supplying a maximum compaction during molding. However this ratio is not enough to prevent the gear tooth from initiation and propagation of cracks. The two modes of failure seen for the gears are tooth root bending fatigue and contact fatigue. Ramesh and Ganesan (1993) used metal matrix composites (MMC) in a railway wheel and compared them with steel and fiber reinforcement plastic (FRP) wheels from a static point of view. They concluded that the deflection in MMC is much lower than that of FRP, but the fundamental frequency of the MMC wheels are higher than those of steel or FRP wheels. Junichi Nozawa et al. (2009) studied the tribology of a metal spur gear and a hybrid gear, in order to reduce noise with greaseless metal gear and plastic gear with smaller rate of tooth failure. The test was at rotation speeds of 1000 rpm. They discovered that the noise is suddenly amplified when a single polymer sheet was spontaneously removed from the gear's surface; and their research indicates that this is due to its low adhesive strength against a shear.

3.2 Polymeric Matrix Composites Gear

Many researchers have studied, fabricated, and discussed the behavior of composite gears as a polymer matrix and glasses or graphite fibre, which named a (PMC) used in engineering applications as gear due to their medium level strength and low density. Kozo (1986) investigated the effect of different types of composite material on the strength of plastic gears. They used glass and carbon fibres in the gear tooth surfaces as reinforcement in order to improve bending strength, epoxy resin as the matrix material. Experimental static and dynamic tests were carried out to evaluate the effect of fibre reinforcements, and it shows the reinforcement is effective in improving the strength of plastic gears. Masaya et al. (1999, 2000, 2003) improved the performance of a plastic gear by using five kinds of carbon fibres and blending it with poly-ether-ether-ketone (PEEK). They evaluated the load capabilities and the wear properties of the reinforcement material used, and the results showed that the carbon fibre reinforced composite gear have superb affinity with PEEK. In 2007 Melick examined the effect of steel and plastic gear transmission with numerical and analytical methods by studying the influence of the stiffness of the gear material on the bending of the gear teeth, the consequences on contact path, load sharing, stresses and kinematics. The tooth bending of the plastic gear teeth results in an increase in the contact path length and considerable changes to load sharing. The root stresses are in dependent of its modulus, and were different from plastic gears from changes in load sharing. Also, the modulus dependent contact stresses, has significant influence on the preliminary and prolonged contact path, inducing very high stress peaks. Furthermore, the FEA results showed that the kinematics of the plastic gears changed dramatically. Hoskins and his group in 2011 presented a study of the dynamic performance of noise emission of polymeric gears. They tested five types of materials; Polyoxymethylene, Unreinforced polyetheretherketone, Carbon–fiber reinforced PEEK, Polyamide, and Glass fiber reinforced, and suggested an optimization of material combinations and the improvement of the techniques that minimizes transmission errors in polymeric gear trains, to give the opportunity of design development.

Senthilvelan and Gnanamoorthy (2007) experimentally studied the effect of various rotational speeds and stress on the performance of unreinforced Nylon 6 spur gears and glass fiber reinforced Nylon 6 spur gears. The result showed that speed has no influence on the gear life on both under low stress levels. At low stress levels, gear tooth root cracking and gear wear were observed, while at high stress levels, the rotational speed influenced the performance of both Nylon 6 and the glass fiber Nylon 6, due to the increase in the gear's surface temperature, which weakens the materials, performance reduction and gear life reduction. It was concluded that the Glass fiber reinforced Nylon 6 gears showed higher performance over unreinforced Nylon 6 gears due its better mechanical strength and resistance to thermal deformation. They also reported and described the computer-aided simulation of unreinforced glass fibre reinforced Nylon 6/6 gear to understand the gating and fibre orientation effect on part shrinkage. Detailed metrological inspection of the molded gears was conducted, and the results were correlated with fibre orientation in the gear and the simulations results (Senthilvelan & Gnanamoorthy, 2008). Mao (2007) carried out experimental investigations and modeled polymer composite (glass fibre reinforced nylon with PTFE). The design method is based on the relationship between polymer composite gears wear rate and surface temperature. A similar test was conducted on non lubricated metal gears, and it was discovered that the polymer gear wear rate dramatically increased when the load reaches a critical rate for a specific geometry. Furthermore, he reported that there are two failure modes that might occur in the polymer composite gears, which is fatigue, or wear. Polymer composite gears have been used in many applications such as the automotive industry, office machines and textile machinery, as well as other gearing industry. It is preferred due to the economical and technical advantages such as its minimal need of grease or lubrication, low production cost, low density, high resilience and internal damping capacity (KMao, 2007).

Huseyin Imrek experimented with plastic spur gears made of Nylon 6 by modifying the width of the gear teeth, shown in Figure 1. He investigated the performances of both the modified and unmodified gears with different loadings with a fixed rotational speed of 1000 rpm.
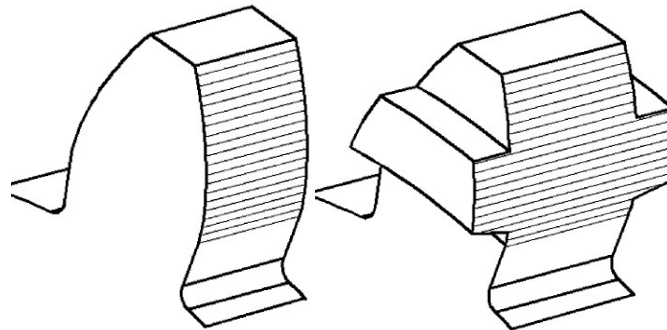

Figure 1. Unmodified and modified gear profile models (HuseyinImrek, 2009)

The purpose of the investigation is to improve the poor heat conduction of gears under high loads and speeds, due to the fact that it decreases the strength and the performance of the gears. From the study, the results showed that the modified gears exhibited lesser tooth temperatures, and its wear rates were significantly reduced compared to unmodified gears. He concluded that the teeth width modification reduced the wear rates on the tooth profile and increased the gear's performance, but the reduction in the tooth's surface temperature is 10-15 ºC, which is considered quite slight (Huseyin, 2009).

Hayrettin (2009) created a modified Polyamide gear tooth by drilling cooling holes at different locations on the gear tooth in order to improve heat distribution in the gear. This experiment showed that this method of heat distribution is effective as the service life of the gear significantly improved compared to standard spur polyamide gears. Figure 2 showed the new design of the gear, and where the failure occurs. However, mass transfer occurred between the holes, so the positions and dimension of the drilled cooling holes must be carefully selected. In general, the thermal conductivity of polyamide gears is abysmal. Furthermore, Zhu and Li (2011) established a finite element model on a straight bevel gear by drilling holes in gears to reduce its weight. Nevertheless, they concluded that straight bevel gears with holes would weaken the mesh impact beneath the vibration compared to the normal straight bevel gear under the same loading and environment conditions. Vilmos Simon (2009) presents an optimal tooth modification for a spiral bevel gear that improves load distribution and decreases the maximum tooth contact pressure.

Figure 2. The damage in newly designed gears (Hayrettin, 2009)

3.3 Fibre Reinforcement Composite Gear

Fibre reinforcement results in high specific strength and stiffness compared to metal matrix composite, depending on different types of fibre (glass, carbon and Kevlar) and their arrangement in the matrix when acting as laminates, which are mostly used in weight-sensitive industry gear applications, offering the highest specific strength and stiffness. However, the growing use of fibre reinforcement composites in many gear transmission applications consist of embedded laminated layers of unidirectional fibers in a matrix, which are very directionally dependent in terms of strength. Composite materials are suitable when complex shape components with lower manufacturing expenses are needed. Hasim Pihtili (2009) investigated the wear resistance and behavior of woven glass fiber and composite materials under different loads, speeds and sliding distances. Antonio and Marcos (1993) used a polyethylene terephtalate to replace a spur gear. The module of the spur gear equals to 2mm/tooth, with a pitch diameter 34mm, and a pressure angle of 20º and the width of 18 mm. Nabi and Ganesan (1993) studied the effect of teeth proximity stiffness while analytically evaluating the root stresses of a gear using the cyclic symmetry approach. In their analysis, an attempt had been made to compare the root stresses with and without considering the effects of the adjacent gear teeth stiffness's using the concept of cyclic symmetry. Furthermore, they analyzed the performance of a composite spur gear made of Glasses/Epoxy using the above approach, and it was discovered that root stresses of cyclic symmetry is less for orthotropic spur gears.

4. Gear Stress Analysis Studies

The manufacturing and designing of bevel gears is currently considered an important field of research, and it is essential applications in robotic transmissions, automobile gears, and in other manufacturing processes. Investigations and experiments in this area are numerous, and current researches gravitate toward enhancing the endurance of the gear drives while simultaneously decreasing the noise. One of the main causes of gear tooth failures is the large tensile stress on the root fillets of a loaded gear tooth. These stresses have the tendency to trim down the gear's service life, and result in catastrophic failure under peak loading conditions. Enormous efforts have been made by previous investigators to relate tensile fillet stresses observed in statically and dynamically loaded gear teeth to the geometric appearance of the tooth. There are a number of approaches used in the past to verify the stresses and deflection in the gear's teeth, Wilfred Lewis made where the first effort to find the tooth root stresses. He based his analysis on a cantilever beam, and assumed that failure will occur at the weakest point of the beam, with him assuming it to be at the cross-section at the base of the gear. At the same time, Heinrich Hertz researched the contact pressures of the teeth, and his research was based on the elastic contact of two cylindrical bodies that determines the contact pressure between a gear and a pinion. With this tendency and experimental studies on bending stress analysis for the gears, the American Gear Manufacturers Association (AGMA) published their own standards based on Lewis's equation. It is more accurate, and calculates all the geometrical factors, which are important in calculating the bending stresses for the gears. These geometrical factors take into account the loading position and the fillet radius tooth of the tip and base. Alexander (2003) detail an engineering method that balances bending stress in the pinion and the gear. In general, the pinion and the gear have diverse tooth shapes and widths, constituting different materials. They presented an equation for equal bending safety factors for maximum bending stresses in both the pinion and the gear, in order to provide equally strong teeth to the pinion and gear. The equation is:

$$Smax1 - kb \cdot Smax2 < \delta s \qquad (1)$$

Where Smax1 and Smax2 are the maximum bending stresses in the fillet area of the pinion and the gear, kb is the bending stress balance coefficient reflecting the difference of material properties and the number of tooth load cycles for the pinion and the gear, and δs is the permissible balance tolerance (typically less than 1%). In their research, different pressure angles were used (25° and 28°), and the results showed that the maximum bending stress is much lower than the standard gear pressure angle (20°). Furthermore, they reported that the bending stress reduction in turn leads to size and weight reduction, longer life, and higher load application for gear, however, the friction effects were ignored in their research. Hasan et at. (2006) analytically studied the elastic–plastic stress analysis on an orthotropic rotating annular disc. The disc is made from metal matrix curvilinear reinforced steel fibers, and they used different angular velocities to enable them to see the separation of the plastic region. The results showed that the radial displacements and the plastic flow at the inner surface have higher values than those at the outer surface. In 2004, Glodez developed a new model to determine the service life of mechanical elements in contact that is showing signs of pitting. They use the finite element method to determine the stress field in the contact area between the gears, and the simulation of fatigue and cracks on the contacting surfaces. The contacting mechanical elements contain crack initiation and propagation required for pit formation. The required number of stress cycles N for the pitting rate of the gear is determined by:

$$N = No + Nf \qquad (2)$$

Where No is the number of stress cycles required for the fatigue crack initiation, and Nf is the number of stress cycles required for the initial crack to propagate to the critical crack length. Ahmad and Ahmet (2007) proposed two dynamic models in order to study the interaction between a gear's surfaces wear and its dynamic response. The model is made up of the influence of the worn surface profiles on dynamic tooth forces, its transmission error, as well as the influence of dynamic tooth forces on the wear profiles. Kumar et al. (2008) investigated the use of asymmetric toothed gear to develop fillet capacity in bending. They also analyzed the maximum fillet stress in order to help improve fillet capacity in bending. In their study, they used a non-standard asymmetric rack cutter for the pinion and the gear. They concluded that the asymmetric gear drive enhances the fillet load capacity of the pinion and the gear at higher-pressure angles.

Michele et al. (2005) and har group described a procedure for analyzing a gear under torque. it's a three step procedure, beginning with manufacturing simulation for the tooth profile of the face gear, followed by the unloaded kinematics simulation to determine the possible contact regions, and finally the computation of the load sharing between all the teeth that is in contact with each other. This stage involves the computation of instantaneous pressure distribution, meshing stiffness and the loaded transmission error. They present a model of a gear, based on analytical simulation, and conducted experimental tests using strain gages and compare with numerical results. A modified bevel gear was used to carry out the strain gage measurements, with the strain gages fitted on the gear with no respect to the nodes of the model. As a result, the stress at the similar position of the strain gauge fitted was not estimated in the experiment.

5. Finite Element Analysis

Finite Element (FE) is a viable engineering method that is capable of solving structural related problems without actually having to construct the structure itself. The method involves discretization of a structure into smaller individual units (i.e. finite elements), which are then reassembled in order to accurately portray the distortion of each finite element under various loading conditions. Each element has an assumed displacement field, and it is imperative that the selection of appropriate elements of the correct size and distributions is made to ensure accuracy of prediction (the FE 'mesh') (Matthews et al., 2003).

A finite-element analysis allows for the exploration of variables and loadings when no analytical model is available. Modelling of physical objects and the discretisation into finite elements allows for a numerical solution that closely predicts the physical behaviour of the actual material, provided that the material model is appropriate and accurate. By using the numerical model, numerous variables can be examined in order to limit the range of practical variables for actual physical testing. The most reliable technique for determining stress and deflection is the finite-element method (FEM). Arafa and Megahed (1999) constructed an FEA model of a spur gear to gather more information on the gear's mesh stiffness. The analysis involves quasi-static meshing conditions, where its compliance is evaluated at discrete meshing positions; with it assumed to be homogeneously isotropic. Their FEA results prove that the deflection of a loaded tooth is proportional to the load location along the tooth profile, and not on the mating tooth geometry, which is determined by the number of teeth, with it being based on a single tooth contact only. Faydor conducted an experimental and numerical investigation on a steel spiral bevel gear. Their main goal was to reduce the levels of noise and vibration of the gear, and they manage to achieve this by the application of tooth contact analysis and stress analysis using the finite element method (Faydor et al., 2006). The gear tooth deflection under an applied load is an important factor that affects the gear design, and it is essential to calculate the tooth profile and the pattern of the load. A student and some other researchers investigated the gear tooth deflection in Laval University Quebec, and they presented a finite-element model for a spur and a straight bevel gear (Gagnon et al., 1997).

Yi and Chia (2011) investigated contact stress for a non parallel axes concave conical involute gear pairs, with the first model being a bevel gear, and the second model a helical gear, using a finite-element analysis. They used the commercial software (ABAQUS), which is able to determine the contact stress of the two 3D deformable gears in order to evaluate the stress distribution on the gear tooth surfaces. The boundary conditions that they used to generate their FE model were that they considered the material isotropic, the stress is in the elastic region of the material, and they neglect the thermal stress, heat generation and the friction loss. In their FEA simulation, they applied 50Nm torque, and they fixed the gear, and gave the pinion a static degree of freedom. However, the FEA model did show the failure mode(s) that can occur. They calculate the Hertzian contact stress from Hertzian formulae and compared the results with FEA simulation.

In 2008, Chao Lin and his team used the finite element software (ABAQUS) to establish a 3DFinite element model of a noncircular gear transmission. They choose ABAQUS because it is one of the most advanced large-scale general finite element software in the world, and has powerful functions for nonlinear analysis, dynamic stress, and contact problem fields. The material used for the oval gear is 45 steel, with a Young's modulus of (2.0×10 N /mm2), Poisson's ratio of (0.3), and a Density of (7.85×10 kg /m2).

6. Linear and Nonlinear FEA Limitations

The linear and nonlinear analyses are two types of FEA. Their main divergence is that in the nonlinear analysis, the displacement is assumed to be large, while in the linear analysis, the displacement is assumed to be very small. The other main difference is that the nonlinear analysis considers the elastic and the plastic behavior of the material and its output to be not necessarily linear, while in the linear analysis, only the elastic linear zone will be considered. Comparing the two analyses, the linear analysis problems are easier to solve, with a low computational rate. Besides that, special load cases and boundary conditions can be utilized in linear analysis, which is inapplicable in nonlinear analysis. Nonlinear analysis is considered as the modeling of real world systems, while linear FE is the idealization of such systems. This idealization can be reasonably satisfactory in some cases, but for special cases, nonlinear modeling is the only option, and this includes straight bevel gear simulations. The sources of nonlinearity depend on geometric nonlinearity, in which the change in geometry is taken into consideration in setting the strain-displacement relations. Material nonlinearity response and possible deformation can occur. The boundary condition nonlinearity, in which the applied force and displacement depends on the deformation of the structure, is also another parameter to that effect. In nonlinear and also in linear FEA, many assumptions are made, due to the lack of information on some physical parameters, or due to the uncertainties about their actual values, such as the exact value of the material's yield strength, and the exact value of the part's thickness. This may lead to a deviation between the results from test experiments and FE models. The sources of deviation can be classified as follows:

1) *Deviation due to material:* Consider that in FEA, isotropic and orthotropic materials are assumed to have homogeneous properties, whereas in reality, there are many factors that may lead to non-homogeneous material properties, for example, imperfections in the microstructure, voids ...etc.

2) *Deviation due to geometry:* FEA assumes that the model's dimensions are uniform along the gear part, whereas this may not be the case in the real world due to the manufacturing processes deviations, which can lead to non-uniform sizing.

3) *Deviation due to load:* Consider that in FEA, a longitudinal axial loading is assumed to be completely perpendicular to the gear's tooth surface, and it is also assumed that the load and torque is perfectly aligned with the gear axis, whereas in reality, these precision cannot be guaranteed.

4) *Deviation due to measurement:* In reality, physically measured quantities are subject to the measuring tool's tolerances, and are also subject to the variation between different samples. This may cause a difference between the measured and the actual values.

The aforementioned sources can lead to a large difference between idealized finite element simulations and reality, especially in nonlinear finite element analysis. The intentional introduction of slight limitation within the nonlinear FE model helps in accounting for the difference between reality and idealization.

7. Summary

As mentioned in the literature, there is a demand for composite materials, as it is important for robotics applications due to the heavy mechanical parts made from conventional materials. Gears are one of the heavy parts in the mechanical structure of industrial robotic arms, it is obvious that combining more than one material to fabricate a composite structure is more efficient. The advantage of using composite gears is the inability of metals and their alloys in meeting today's gears' requirements. For example, carbon fiber matrices has better mechanical properties, higher specific strength (strength to density ratio), higher specific modulus, and better fatigue and wear resistance compared to metals. They also have higher specific energy absorption, which is imperative in industrial parts design, due to the fact that it will reduce weight, cost, noise and vibrations. Moreover, polymeric matrix composites (PMC) have limited transmission gearing and low loading abilities. In addition, it has been specified that the PMC have low surface temperature, and beyond a specific critical temperature value, sharp failures will occur. As a result, PMC gears have low load carrying capabilities, short service life, and poor heat resistance, rendering it inefficient for use in industrial applications. As a result, the present work will provide evidence that a new form of cheap material may be useful for designing a new type of lighter and stiffer gear, designed for robotic arm applications or any power transmission application.

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