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FEM ANALYSIS OF POLYPROPYLENE SPUR GEAR HAVING ASYMMETRIC INVOLUTE GEAR TEETH

Amir Khan*1
*1, Department of Mechanical Engg., Faculty of Engg., Pranveer Singh Institute of Technology Agra - Delhi National Highway - 2, Bhauti, Kanpur, Uttar Pradesh 209305

ABSTRACT
To satisfy the demand for lighter, faster, quieter, more durable, cost-effective gears, innovative designs increasingly include the use of high-performance plastics. In applications ranging from automotive components to office automation equipment, engineering polymers successfully replace metals even in fine critical gears and contribute superior performance. As design engineers worldwide discover the remarkable benefits of polymers for gears, they also discover that identifying the right product for the job can sometimes be a difficult proposition. In this paper, we focus on the properties of polypropylene concentrates and fibers modified by inorganic additive. Polypropylene staple fibers are assigned as reinforcement of concrete to transform and absorb deformation energy. Modification of polypropylene fibers is necessary to ensure more intense anchoring of fibers in cement matrix. Polypropylene gears with an asymmetric involute gear tooth form were analyzed to determine their bending stresses relative to symmetric involute gear tooth designs. Asymmetric and baseline (symmetric)-toothed polypropylene gear test specimens were designed and tested to determine their single-tooth bending strength. Test results demonstrated higher bending strength for the asymmetric tooth form compared to baseline designs.

Keywords: Polypropylene,Asymmetric, PP fiber

INTRODUCTION

The modern era of research and development of fiber reinforced concrete (FRC) was initiated in the early 1960´s by Romualdi, Batson and Mandel. In the present fiber reinforced concrete is firmly established as worldwide most commonly used construction material. The expression fiber-reinforced concrete is by AC1 116R, Cement and Concrete Terminology defined as concrete containing dispersed randomly oriented fibers (Sideris 2009, Zollo 1997, Banfill et al. 2006). This three-dimensional reinforcement of the concrete provides that by usage of fibers concrete becomes more tough and durable. The practical function of fibers is from a constructional point of view, to protect composite against sudden failure at the crack initiation in matrix. The tension is transferred to the fibers until the ultimate strength of fibers is reached (Noumowe 2005, Singh 2004). Modern engineer have as a main objective the attempts to modify the properties of concrete by the inclusion of fibers to improve rheology or plastic cracking characteristics of the material in the fresh state or up to about 6 hours after casting, tensile or flexural strength, impact strength and toughness, durability and to control cracking and the mode of failure by means of post-cracking ductility (Hannant 2003). Properties and character of fiber reinforced concrete depend on the type of material, fiber geometry, binder formulation, fiber distribution, fiber orientation and fiber concentration. Based on used material type there are four categories of fibers used for concrete reinforcing: steel fiber, glass fiber, synthetic fiber including carbon fibers, and natural fiber (Zollo 1997). Although glass, carbon and steel fibers have been extensively used in cement matrices, this paper focuses on the addition of polypropylene fibers. Polypropylene fibers are used as a reinforcing agent in construction applications for many years.

In concrete PP fiber is used in a wide variety of applications in general constructions and specifically in ground-floor slabs. Specific uses have included precast products and situations where fire resistance is important. The latter is achieved by the fibers melting and leaving channels in the concrete though which steam can escape, thus improving the spalling resistance. Utilization of polypropylene fibers alters characteristics of concrete in a very beneficial way. Result is, that PP fibers have effectively improved concrete's flexural strength, compressive strength, bonding strength, dynamic performance, while reduced the water penetration and mass loss due to abrasion. The fatigue life of concrete is also prolonged (Hannant 2003, Sun 2009, Tapkin 2006).

Extensive use has been applied in the construction industry of small quantities (0.1 percent by volume) of short (<25 mm long) fibrillated monofilament polypropylene fibers to alter the properties of the fresh concrete, notably to reduce the extent of plastic shrinkage cracking should it occur. More intense anchoring of polypropylene fibers in cement matrix is reached by physical and chemical modification. Addition of sufficient additive ensures that fibers are consistently fixed in matrix. This leads to expressive improve of functional of PP fibers in relation to transmission and absorption of deformation energy to form and load silica composites.

The design intent of asymmetric PP gear teeth is to improve performance of the primary drive profiles at the expense of performance of the opposite-coast profiles. In many cases the coast profiles are more lightly loaded and only for a relatively short duration. Asymmetric tooth profiles make it possible to simultaneously increase the contact ratio and operating pressure angle in the primary-drive direction beyond the conventional gears' limits. The main advantage of asymmetric PP gears is contact stress reduction on the drive flanks resulting in reduced gear weight and higher torque density.

Areas addressed in this thesis include analysis, design, and testing of PP gear test specimens with asymmetric teeth. Conventional symmetric tooth specimens were also produced and tested to provide a baseline for comparison. The design and manufacture of the gear specimens is representative of office automation equipment gears. Testing included single tooth bending tests of both the asymmetric and baseline gears.

TEST SPECIMEN GEARS DESIGN AND ANALYSIS

Typically in applications ranging from automotive components to office automation equipment, engineering polymers successfully replace metals even in fine critical gears and contribute superior performance. The design intent of asymmetric gear teeth is to improve performance of the primary drive profiles at the expense of performance of the opposite-coast profiles. In many cases the coast profiles are more lightly loaded and only for a relatively short duration. Asymmetric tooth profiles make it possible to simultaneously increase the contact ratio and operating pressure angle in the primary-drive direction beyond the conventional gears' limits. The main advantage of asymmetric gears is contact stress reduction on the drive flanks resulting in reduced gear weight and higher torque density.

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TEST SPECIMEN GEARS SPECIFICATION:

S.No	Gear Specification	Symbol	Formula	Gears	
				Symmetric teeth	Asymmetric teeth
1	Module	m		3	3
2	Reference pressure angle Drive side	α		25	30,35
3	Reference pressure angle Coast side	α		25	25
4	No. of teeth	z		12	12
5	Pitch diameter,	d_p	zm	36	36
6	Drive base diameter	d_b	$d_p \cos \alpha$	32.62	29.48
7	Coast base diameter	d_b	$d_p \cos \alpha$	32.62	32.62
8	Face width	b	$A_0/3$	18	18
9	Tooth thickness	t	1.571m	4.713	4.713

DESIGN OF ASYMMETRIC SPUR GEAR TEETH:

The two profiles (sides) of a gear tooth are functionally different for many gears. The workload on one profile is significantly higher and is applied for longer periods of time than for the opposite one. The design of the asymmetric tooth shape reflects this functional difference.

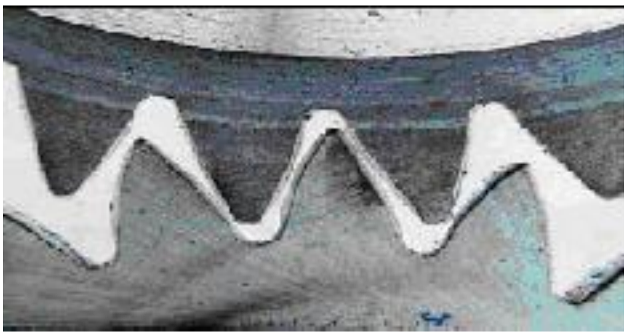

Fig.: Asymmetric spur gear.

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The design intent of asymmetric gear teeth is to improve the performance of the primary contacting profile. The opposite profile is typically unloaded or lightly loaded during relatively short work periods. The degree of asymmetry and drive profile selection for these gears depends on the application.

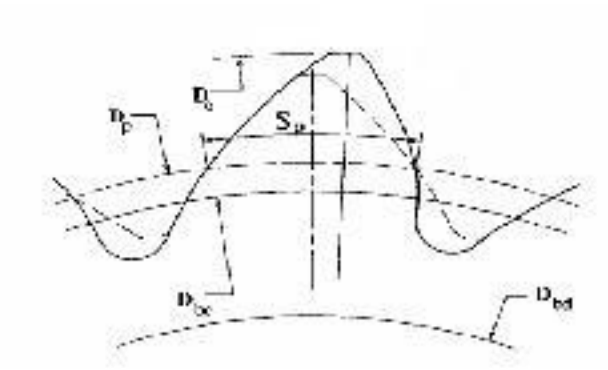

Fig.: Asymmetric spur gear with different base circles.

The difference between symmetric and asymmetric tooth is defined by two involutes of two different base circles D_{bd} and D_{bc}. The common base tooth thickness does not exist in the asymmetric tooth. The circular distance (tooth thickness) S_p between involute profiles is defined at some reference circle diameter Dp that should be bigger than the largest base diameter.

Asymmetric gears simultaneously allow an increase in the transverse contact ratio and operating pressure angle beyond the conventional gear limits. Asymmetric gear profiles also make it possible to manage tooth stiffness and load sharing while keeping a desirable pressure angle and contact ratio on the drive profiles by changing the coast side profiles. This provides higher load capacity and lower noise and vibration levels compared with conventional symmetric gears.

It is found that asymmetric tooth geometry (with larger pressure angle on drive tooth side) allow for an increase in load capacity while reducing weight and dimensions for same types of gears. Maximum bending and contact ratio depending on number of tooth and pressure angle of the drive side, for asymmetric drives is estimated, tooth form and stress concentration factors for different parameter is also determined. The determination of the tooth form and stress concentration factors for asymmetric tooth has been accomplished for each different parameter (pressure angles, tool radius, rack shift, etc.). Direct gear design method for spur and helical involute gear is developed which allows analysis of a wide range of parameters for all possible gear combinations to find out the most suitable solution for a particular application.

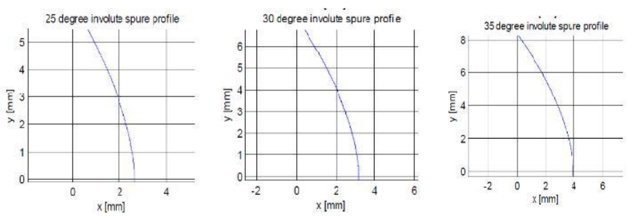

Fig. Involute profiles with different pressure angle

CAD MODELLING

The Creo-2 parametric CAD solid modeling software was extensively used for the generation and analysis of the differential and driveline components .The most complex part of the gear modeling process is in creating the involute curve. This is the curve that traces the path of the contact point between two gears in mesh such that the ratio of speeds between the two gears is always constant.

Figure: Symmetric spur gear

Figure : Asymmetric spur gear

TYPICAL ENGINEERING PROPERTIES OF POLYPROPYLENE

S.NO.	General Properties	English Units	SI Units
1	Density	56.1 – 57.4 lbs/ft3	0.898-0.920 g/cm3
2	Modulus of Elasticity(Homopolymer)	183,000 psi	1,300 MPa
3	Poisson's Ratio	0.45	0.45
4	Hardness	55 – 65	55 – 65
5	Thermal conductivity		0.16 W/m /°K
6	Melting Point	320 - 329 °F	160 - 165 °C

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FEM ANALYSIS:

Finite Element methods are numerical techniques of solving differential equations in engineering problems. The theories pertaining to the generation of gear tooth surfaces as well as the theory of meshing are based on the differential geometry concept of the envelope to a family of surfaces. Finite element methods involve the discretization of any one region into a finite number of tiny areas over which continuous quantities such as displacement or stress can be approximated. In the case of bevel gear design, finite element models can be used both for the analysis of stresses on different parts of gear teeth.

ANSYS 14 was used to perform the analysis. To begin, each gear is decomposed in finite elements and node then load is applied. To simulate a continuous force is applied along the side of the gear tooth. The load itself is a point load being at the large end of the tooth along pitch circle.

FEM Analysis of symmetric spur gear having pressure angle 25/25:

For the analysis of symmetric spur gear having pressure angle 25/25 .It decomposed in finite elements and node then maximum permissible load is applied at pitch circle diameter of gear. A graphical representation of actual stress developed in various region of tooth is showed. With the help of stress distribution we can determine which region of tooth maximum stress is developed. This maximum stress is actual permissible stress which can apply to the pinion gear without failure.

S_b= maximum tangential force applied on the tooth without bending failure.

S_b= 0.5 N

A tetrahedral mesh with 3468 elements and 18026 nodes was used to discretize the pinion

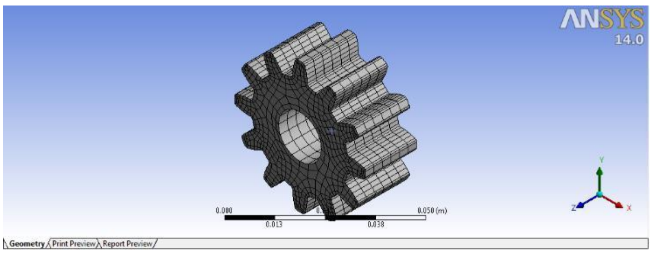

Figure: Tetrahedral mesh of symmetric spur gear having pressure angle 25/25

The stress distribution plot suggests that the root section of the tooth on the same side as the applied force experiences tension whereas the root section on the opposite side experiences compression. The color stress distribution plot give the value of actual stress developed in various region of tooth. With the help of this stress distribution we can determine which region of tooth maximum stress is developed.

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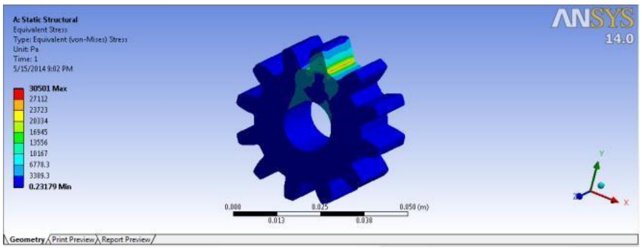

Figure : FEM analysis of symmetric spur gear having pressure angle 25/25

It is being observed from above stress distribution the value of maximum stress developed at root fillet region of tooth with maximum value of σ_b =30501 P_a

FEM Analysis of asymmetric spur gear having pressure angle 25/30:

Similarly for asymmetric spur gear having pressure angle 25/30 .It decomposed in finite elements and node then maximum permissible load is applied at pitch circle diameter of gear at drive side. A graphical representation of actual stress developed in various region of tooth is showed. With the help of stress distribution we can determine which region of tooth maximum stress is developed. This maximum stress is actual permissible stress which can apply to the pinion gear without failure. S_b= maximum tangential force applied on the tooth without bending failure.

S_b= 0.5 N

A tetrahedral mesh with 8198 elements and 14964 nodes was used to discretize the asymmetric spur gear

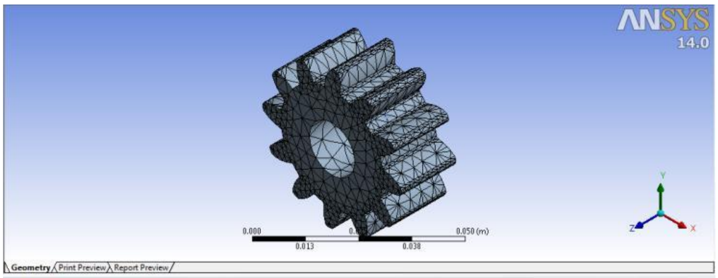

Figure: Tetrahedral mesh of asymmetric spur gear having pressure angle 25/30

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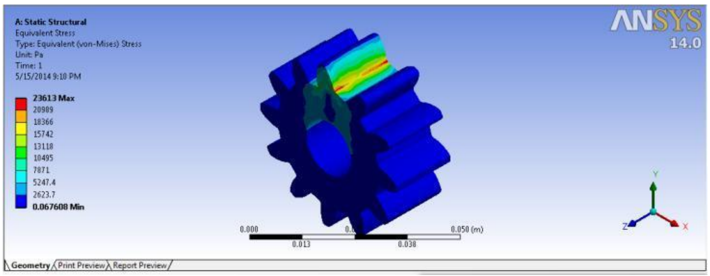

Figure: FEM analysis of asymmetric spur gear having pressure angle 25/30

It is being observed from above stress distribution the value of maximum stress developed at root fillet region of tooth with maximum value of σ_b =23613 P_a

FEM Analysis of asymmetric spur gear having pressure angle 25/35:

Similarly for asymmetric spur gear having pressure angle 25/35 .It decomposed in finite elements and node then maximum permissible load is applied at pitch circle diameter of gear at drive side. A graphical representation of actual stress developed in various region of tooth is showed. With the help of stress distribution we can determine which region of tooth maximum stress is developed. This maximum stress is actual permissible stress which can apply to the pinion gear without failure.

S_b= maximum tangential force applied on the tooth without bending failure.

S_b= 0.5 N

A tetrahedral mesh with 8198 elements and 14964 nodes was used to discretize the asymmetric spur gear

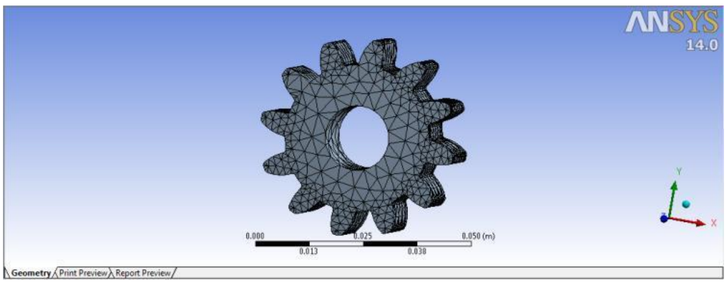

Figure: Tetrahedral mesh of asymmetric spur gear having pressure angle 25/35

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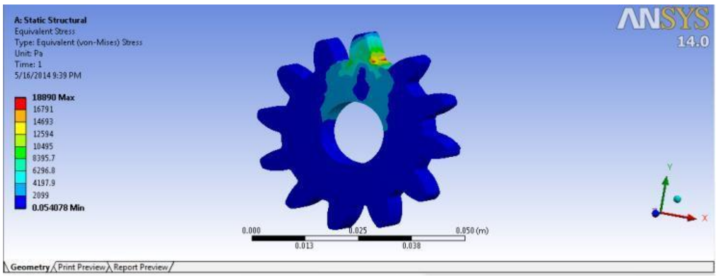

Figure : FEM analysis of asymmetric spur gear having pressure angle 25/35

It is being observed from above stress distribution the value of maximum stress developed at root fillet region of tooth with maximum value of σ_b =18890 P_a

RESULT

Comparison between symmetric gear & asymmetric gear at different pressure angle:

S.No	Gear model with different pressure angle (drive/coast)	Von misses, Pascal (P_a)
1	25/25	30501 P_a
2	25/30	23613 P_a
3	25/35	18890 P_a

All modeled gear is analyzed for stress by above mentioned procedure. Different values of stress for each model is shown in table.

CONCLUSION

It can be concluded from above table that as the value of pressure angle increases the profile becomes more curved; as a result it will increase the base of the gear tooth and reduce the value of tip thickness at addendum circle of the gear tooth. The increased base increases the bending strength but at the same time reduction in tip thickness decreases the tip strength.

It has been found that as drive/coast side pressure angle increases the contact ratio and tooth peaking decreases, which means maximum pressure angle is constraint by the safe contact ratio and tooth peaking effect results decrease in weight

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