Development and Testing of Coconut Shell Particle Reinforced Epoxy Composite for Power Transmission Applications

G H Manjunatha Chary[1], K Sabeel Ahmed[2]
Assistant Professor[1], Professor[2], Department of Mechanical Engineering
Jawaharlal Nehru National College of Engineering, Shivamogga – 577204, Karnataka, India

Abstract: *In the present work, coconut shell particle reinforced epoxy (CSPE) composite has been investigated by selecting the optimum grain size and optimum particle volume fraction for fabrication of gears and pulleys. Composites were fabricated using open mould process for 0.25 mm grain size with particle volume fraction of 40%. Composites spur gears and pulleys were designed and fabricated from CSPE composite and possibility of their use in transmission system of a machine tool has been investigated. For this purpose, a medium duty Lathe was selected and the existing steel gears in the change gear train were replaced with composite gears. Also the existing metal pulleys mounted on the source (motor) and its driven pulley in the same machine was replaced with the composite pulleys. Various turning operations were then performed on the lathe on both ferrous and non-ferrous metals and the performance of composite gears and pulleys were observed. In addition to this, an attempt was also made to evaluate the in-plane elastic properties of the composite both analytically and experimentally. The evaluated elastic properties were used to carry out the finite element static analysis of gear.*
Keywords: *CSPE Composites, Elastic Properties, Power Transmission, CSPE Composite gears, CSPE Composite Pulleys.*

I. Introduction

In the recent years, as a result of rising environmental awareness, natural fillers (bio-based) have been in huge demand as a reinforcing material in the fabrication of polymer composites especially for substitution to wood products. Many researches have been taken up for the best use of natural materials in the place of synthetic materials because of their advantages such as low cost, low density, biodegradability, and renewability. Furthermore, the composites made of natural fillers are hard, stiff, and easily machinable. The use of natural fillers as reinforcement material in the fabrication of polymer composites can compensate the scarcity of wood resources. Several researchers have made an attempt to investigate the mechanical properties of composites [1-8]. Aji et al [1] investigated the mechanical properties of groundnut shell based on varying volume of shell and Urea formaldehyde. Test samples were produced from aluminum mould. The tensile and compression test were conducted. Several proportions by volume of shell and Urea formaldehyde were used and an established volume of 12% volume of shell plus 79g of urea formaldehyde in the sample gives the best or optimum composite. Kranthi et al [2] investigated the development and wear performance evaluation of epoxy based composites filled with pine wood dust. The dust particles of average size 100 μm are reinforced in epoxy resin to prepare particulate filled composites of three different compositions with 0, 5 and 10 wt% of pine wood dust. Dry sliding wear trials were conducted based on design of experiments using a standard pin-on-disc test set-up. They concluded that pine wood dust possesses good filler characteristics as it improves the sliding wear resistance of the polymeric resin. Raju et al [3] have studied tensile, impact, bending and moisture absorption properties of groundnut shell reinforced epoxy composites. Composite boards were fabricated by groundnut shell particles of different grain sizes and epoxy resin with volume percentages of 70:30, 65:35, and 60:40. Results show that a useful composite with moderate strength could be successfully developed using groundnut shell particles as a reinforcing agent in epoxy matrix. These composites are found to have good mechanical properties. Sarki et al [4] appraised the possibility of using coconut shell particle as filler in epoxy resin with different weight fractions (10%, 20% and 30%). The results showed that there is an increase in the tensile properties and marginal decrease in impact strength with the increase in coconut shell particles content. Scanning electron microscopy (SEM) observation of the composite showed that there is a good interfacial bonding between coconut shell particles and epoxy. Imoisilli et al [5] determined the possibility of using agricultural waste materials, as reinforcing fillers in thermosetting polymer composite, the effects of cocoa-pod filler (CPF) volume fraction on the tensile properties of Epoxy composite was investigated, different filler concentrations (viz. 5 to 30 weight %) were fabricated, test results show that tensile strength, load at break, of the composite decreases with filler concentration while elastic modulus of the composite increases with increase in filler concentration. Agunsoye et al [6] studied the morphology and mechanical properties of coconut shell reinforced polyethylene composites. Coconut shell reinforced composite was prepared by compacting low density polyethylene matrix with 5% - 25% volume fraction coconut shell particles and investigated on the effect of the particles on the mechanical properties. They concluded that the hardness of the composite increases with increase in coconut shell content though the tensile strength, modulus of elasticity, impact energy and ductility of the composite decreases with increase in the particle content. Sareena et al [7] conducted tension test on composites made from coconut shell powder (CSP) as filler in natural rubber (NR). Filler loading was varied between 10-40 parts per hundred (phr). Two sets of samples were prepared; one with particle size ranging between 0-45 µm and other between 45-90 µm. The tensile strength and modulus was found to be maximum at 10 phr of CSP/ NR, irrespective of particle size. Manjunatha et al. [8] characterized the mechanical properties of coconut shell particle reinforced epoxy composites. Results revealed that properties are found to decrease with the increase in the filler particle size and filler volume fraction. CSPE composite with 40% filler volume fraction and 0.25 mm particle size exhibited highest values. A brief of review of literature reveal that, although enormous amount of work has been carried out on natural materials. The work on coconut shell particle reinforced epoxy composites is still under research level. Further, most of the authors evaluated the mechanical properties of composites at the specimen level and not much consideration is given regarding practical applications of these composites. This motivated us to take up this work.

II. Materials

Fully matured coconuts shells were first cleaned and crushed into smaller grains. These smaller grains were then subjected to repeated grinding in a pulverizing machine, after passing through cyclones and vibratory sieves fitted with phosphor-bronze mesh. Based on the work carried out earlier [8], 0.25mm is the optimum grain size and 40% is the optimum particle volume fraction. Hence, in this work the grains are drawn out to a size of 0. 25mm.The bulk density of coconut shell particle was determined to be 0.745g/cc which closely matches with the value given in article [7]. Epoxy resin LY 556 and hardener HY 951 in the ratio 10:1 was used as matrix material. Melamine resin or melamine formaldehyde (also shortened to melamine) was also used in the epoxy to melamine ratio of 20:1, to increase the rate of curing, bonding strength and to improve the surface finish of the developed composites. The epoxy resin, hardener, and melamine were procured from M/s Insulation house, Bangalore, India.

1. Fabrication of Composite

Composites were prepared with filler (coconut shell particles) volume fraction of 40 % and 0.25mm size of the coconut shell particles. The density of the composite was determined by water displacement method. Wear and hardness are the importance properties of material required for its application as gears and pulleys. Hence, wear and hardness tests were carried out using fabricated composite boards as per ASTM standards. The results of wear tests and hardness tests are presented in the Table 1.

Table 1. Important Properties of CSPE composites

Composite	Density (kg/m³)	Shore Hardness Value	Specific Wear Rate [mm³/Nm]
CSPE Composite with 0.25mm particle size and 40% particle volume fraction.	933	82.33	0.000075

The fabricated CSPE composites with 0.25mm particle size and 40 % particle volume fraction exhibited better hardness and wear property as presented in Table 1 [8]. The same composition is used for the fabrication of gears and pulleys. Cylindrical composite samples (gear and pulley blanks) for generation of gears and pulleys were fabricated using cylindrical molds in the form of pipes. The volume of the mold cavity required was estimated. The diameter of the mold cavity corresponds to the outer diameter of the gear and length of the mold cavity corresponds to the width of the gear, with necessary allowances for machining.

2. Evaluation of Elastic Properties

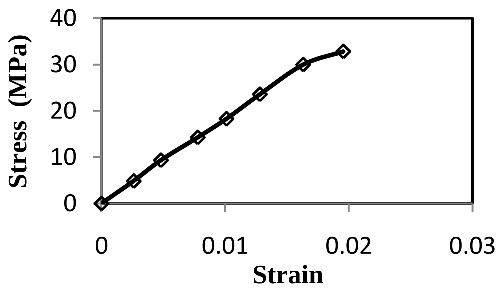
Elastic properties are the important quantities required in the design and analysis of composites. The coconut shell particle filled epoxy composite is a particulate composite and is isotropic in nature having two independent elastic constants namely, Young's modulus and Poisson's ratio. Since the magnitude of these constants for the composite under consideration (40% filler volume fraction and 0.25 mm particle size) is not available in the open literature, it has been evaluated for further use in finite element modeling and analysis.

3. Experimental Evaluation

Young's modulus and Poisson's ratio were evaluated by conducting tension test on composite samples as per ASTM standard D638. For determining the Poisson's ratio, strain gauges (G.F -1.9) were mounted on the samples in longitudinal (loading) and transverse directions and strains were measured using strain indicator.

Tensile tests were conducted on Universal Testing Machine (FIE make) having a capacity of 50 KN. Each specimen was clamped in grips and loaded by uni-axial tension.

Figure 1 shows the typical stress-strain diagram. Young's modulus of elasticity 'E' was calculated by taking the slope of the initial portion of stress-strain curve within the elastic limit.



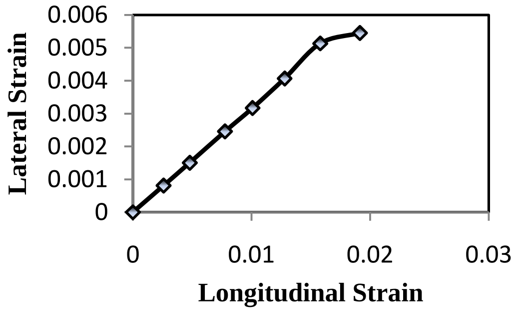


Figure 1.Stress-Strain diagram

Figure 2. Lateral strain –Longitudinal Strain

The corresponding values of strains in the longitudinal direction and in lateral direction were recorded at various load intervals within the elastic limit and a graph was plotted as presented in Figure 2. Poisson's ratio 'γ' was determined from the slope of lateral strain to longitudinal strain.

Modulus of Rigidity 'G' was determined using equation (1) using the experimental values of Young's modulus and Poisson's ratio.

$$G = \frac{E}{2(1+\gamma)} \quad \text{------------------------- (1)}$$

Table 2. Experimental values of Young's Modulus and Poisson's Ratio of CSPE composites.

Composite	Young's Modulus (GPa)	Poisson's Ratio
CSPE Composite with 0.25mm particle size and 40% particle volume fraction.	1.9517	0.314

4. Design of CSPE Composite Gear

6.1 Calculation of Torque

Medium duty lathe (PL-4) of Kirloskar lathe is chosen to conduct the performance test for spur gears developed from CSPE composite by replacing the existing gears made from alloy steel. Figure 3 shows the transmission system of the lathe.

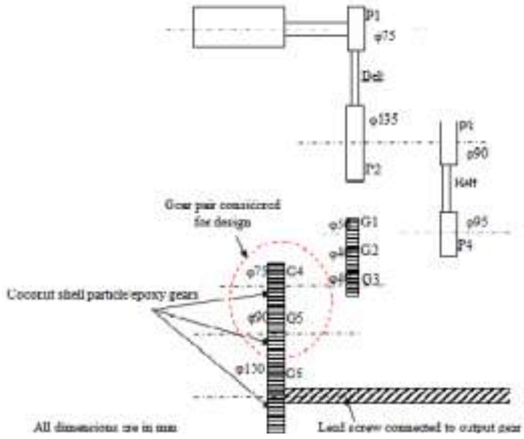


Figure 3. Transmission system of PL-4 Lathe (Kirloskar make)

Nomenclature

P	Power of the motor	0.75kW
N	Speed of motor	1440 rpm
ω_1	Velocity ratio between the pulleys P1 and P2	
d_{p1} and d_{p2}	Diameters of pulleys P1 and P2	
Z_{G4}	No. of teeth on pinion	25
Z_{G5}	No. of teeth on Gear	30
d_{G4}	Diameter of Pinion	75 mm
d_{G5}	Diameter of Gear	90 mm
N_{G4}	Speed of Pinion	1060 rpm
N_{G5}	Speed of Gear	883.33 rpm
α	Pressure Angle	20° involute
G_R	Gear Ratio	1.2
m	Module	3 mm
v	Pitch Line velocity	
C_v	Velocity factor	
y_{G4}	Lewis form Factor	
σ_{ind}	Induced stress in the pinion	
F_d	Dynamic load on gear	
F_{G4}	Tangential tooth load on the pinion	

Torque transmitted by pulley P1, T1 can be calculated using equation (2)

$$T_1 = \frac{9.55 \times P \times 10^6}{N_1} \text{ N-mm} \quad \text{---------------- (2)}$$

Torque available at the pulley P2 can be calculated using the equation (3)

$$T_2 = T_1 \times \omega_1 \quad \text{--------------- (3)}$$

ω_1 can be calculated using equation (4).

$$\omega_1 = \frac{d_{p2}}{d_{p1}} \quad \text{----------------- (4)}$$

Where, d_{p1} and d_{p2} are the diameters of pulleys P1 and P2 respectively.

The pulleys P2 and P3 are compound pulleys and hence torques available at both these pulleys is same. The toque available at other pulleys and gears are calculated in the same way. The details of torque calculated at each pulley and gear are presented in Table 3.

Table 3. Torque calculation at various pulleys and gears in the transmission system

Pulley(P)/Gear(G)	**No. of Teeth**	**Diameter (mm)**	**Speed (rpm)**	**Velocity Ratio Between adjacent pulleys/gears**		**Torque available at the pulley/gear (N-mm)**	
				Designation	**Magnitude**	**Designation**	**Magnitude**
P1	------	75	1440	---------	--------	T_{P1}	4973.95
P2	------	135	800	ω_1	1.8	T_{P2}	8952.3
P3*	------	90	800	ω_1	1.8	$T_{P3} = T_{P2}$	8952.3
P4	------	95	758	ω_2	1.05	T_{P4}	9449.65
G1**	28	56	758	ω_2	1.05	$T_{G1} = T_{P4}$	9446.65
G2	20	40	1060	ω_3	0.7142	T_{G2}	6749.75
G3	20	40	1060	ω_4	1.0	T_{G3}	6749.75
G4**	25	75	1060	ω_5	1.0	$T_{G4} = T_{G3}$	6749.75
G5	30	90	883	ω_6	1.2	T_{G5}	8099.7
G6	50	150	529	ω_7	1.66	T_{G6}	13499.5

*Compound pulley, **Compound gear

6.2 Specifications of CSPE composite gears

Gears G4 and G5 are replaced with CSPE composite gears and are considered for the design (Figure 6).

6.3 Checking the gears for the induced stresses

Since the material for both pinion and gear is same, the pinion is assumed to be weaker and the design is based on pinion.

Pitch Line velocity '*v*' can be calculated using equation (5)

$$v = \frac{\pi \times d_{G4} \times N_{G4}}{60000}$$
---------------- (5)

Assuming carefully the cut gears, C_v can be calculated using equation (6)

$$C_v = \frac{4.5}{4.5 + v}$$
---------------- (6)

The face width 'b' of pinion may be assumed in the range 9.5m ≤ b ≥ 12.5m. For this case, face width is assumed as 11m.

$$y_{G4} = 0.154 - \frac{0.912}{z_{G4}} \quad \text{for } 20^\circ \text{ full depth involute gear}$$

The induced stress in the pinion from Lewis equation is given by the equation (7).

$$\sigma_{ind} = (\sigma_d \times C_v) = \frac{2 \times T_{G4}}{m^3 \times k \times \pi \times y_{G4} \times Z_{G4}}$$

Where, k = b/m ----------------- (7) The induced stress from equation (7) was found to be 15.47 N/mm^2.

The allowable bending stress ($\sigma_{allowable}$) for CSPE composite is 52 N/mm^2 [8].

Since $\sigma_{induced} < \sigma_{allowable}$, the pinion is safe.

6.4 Checking the gear for dynamic and wear load

The dynamic load can be calculated from Buckingham equation (8)

$$F_d = F_{tG4} + \frac{K_3 \times v(C \times b + F_{tG4})}{K_3 \times v + \sqrt{(C \times b) + F_{tG4}})}$$
-- -------------- (8)

The tangential tooth load on the pinion calculated from equation (9)

$$F_{tG4} = \frac{2 \times T_{G4}}{d_{G4}}$$
----------------- (9)

K_3 is 20.67 for 20^o full depth involute gear

C is the dynamic factor given by the equation (10)

$$C = \frac{K \times e}{\frac{1}{E_{G4}} + \frac{1}{E_{G5}}}$$
---- ----------- (10)

Where 'K' is a factor depending upon form of teeth = 0.111 for 20^o full depth involute system.

'e' is the tooth error = 0.025 for carefully cut gear with module upto 4 mm.

E_{G4} and E_{G5} are the flexural modulus for the material of pinion and gear respectively and is equal to 4765.13 MPa for CSPE composites [8].

The value of dynamic load calculated using equation (8) is found to be 452.42 N

The wear load can be calculated using equation (11)

$$F_w = d_{G4} b Q K' \quad \text{----------------- (11)}$$

Where, Q is the ratio factor given by the equation (12)

$$Q = \frac{2 Z_{G4}}{Z_{G4} + Z_{G5}}$$

----------------- (12)

K' is the load stress factor given by equation (13)

$$K' = \frac{(\sigma_{es})^2 \sin\phi}{1.4} \left(\frac{1}{E_{G4}} + \frac{1}{E_{G5}} \right)$$

------------------ (13)

Where, φ is pressure angle (20°)

σ_{es} is the surface endurance limit given by the empirical equation (14)

$$\sigma_{es} = 2.8 \times BHN - 70 \text{ N/mm}^2$$

--------------- (14)

Hardness of CSPE composite is determined to be 92.33.

The wear load calculated from equation (11) was found to be 11990.265 N.

Since wear load of 11990.265 N is greater than the dynamic load of 452.42 N, the design is safe.

Other geometric parameters of the gear are as follows,

Addendum: 1.0 × m
Working Depth: 2 × m
Addendum: 1.25 × m Whole Depth: 2.25 × m
Tooth thickness: 1.5708 × m
Clearance: 0.25 × m
Tooth Space: 1.5708 × m
Fillet radius: 0.4 × m

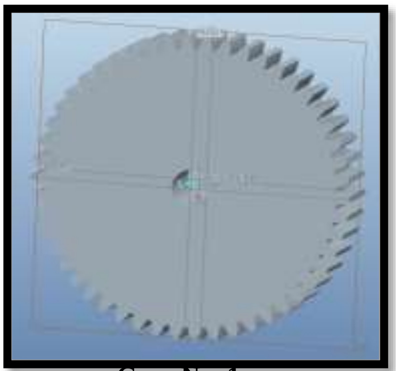
Where, m is the gear module.

5. Finite Element Analysis of CSPE composite spur gear

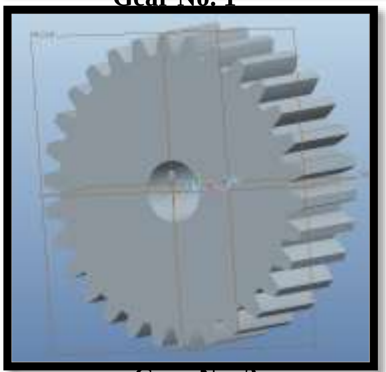
Finite element analysis has been carried out to determine the stress distribution pattern in the gear teeth using ANSYS 14.0. Three different gears have been considered for the analysis with diameters of 75mm, 90mm and 150 mm having number of teeth 25, 30 and 50 respectively as shown in Figure 4. SOLID 186 and SURF 156 elements are used to model the gear teeth. The gear geometry is created using 3-D modeling software PRO E CREO-5 according to dimensions presented in Table 4.

Table 4. Dimensions of three gears considered

Gear No.	Number of Teeth	Addendum Circle Diameter (mm)	Base Circle Diameter (mm)	Pitch Circle Diameter (mm)	Shaft Diameter (mm)	Face width of the Gear (mm)
1	50	156	144	150	19	33
2	30	96	84	90	19	33
3	25	81	44	75	19	33



Gear No. 1



Gear No. 2

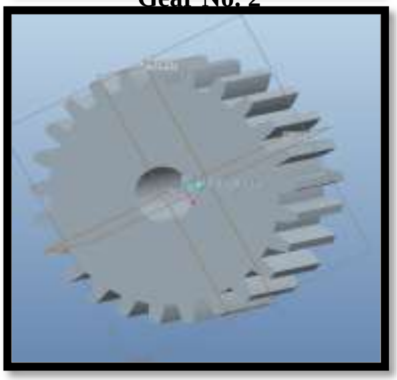
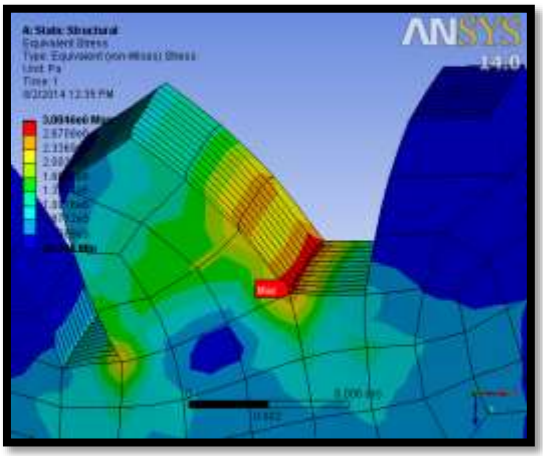


Figure 4. Finite Element Models of Spur Gear

The gear tooth has been modeled as cantilever. The teeth are constrained at the rim and a tangential load of 180 N (obtained from design) has been applied to one of the teeth at the highest point of contact to determine the stress distribution. The stress distribution pattern in three different gears obtained from finite element analysis are shown in Figures 5(a), 5(b) and 5(c) respectively. The maximum stress is induced at the root of gear teeth.



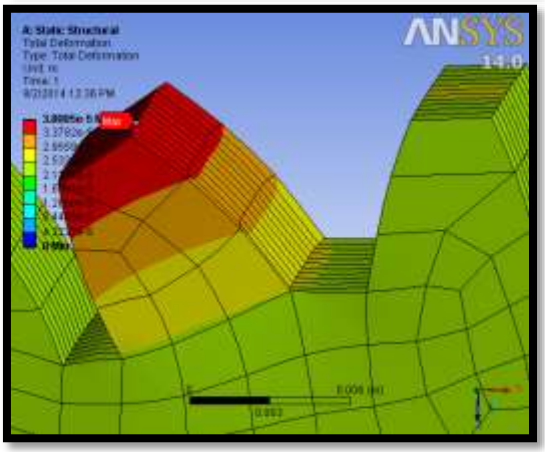
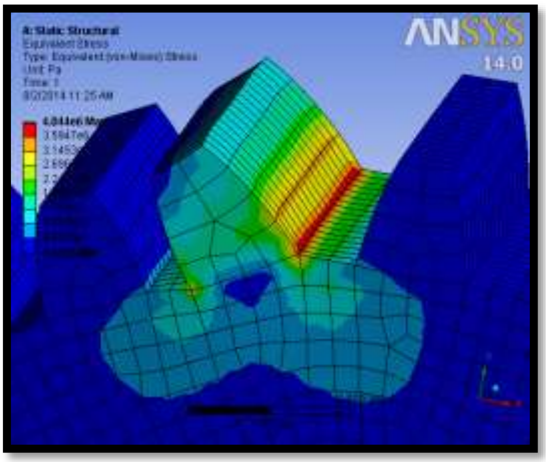


Figure 5(a). Von Mises Stress distribution and total deformation in Gear 1.



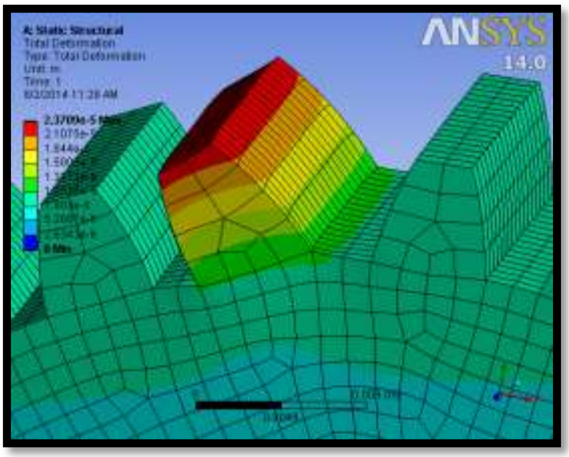
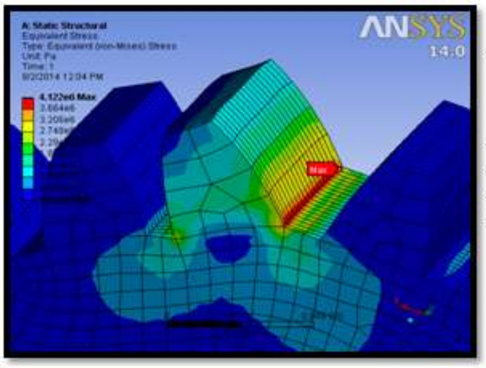


Figure 5(b). Von Mises Stress distribution and total deformation in Gear 2



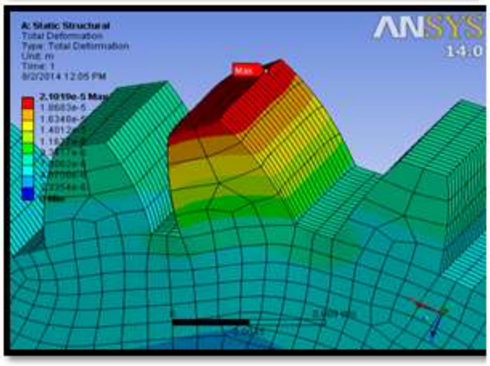


Figure 5(c). Von Mises Stress distribution and total deformation in Gear 3

The details of the analysis are presented in Table 5.

Table 5. Statistics of the analysis carried out for different gears

Statistics	Gear No.1	Gear No.2	Gear No.3
No. of nodes generated	178018	207609	187841
No. of Elements generated	39919	47260	42864
Von Mises Stress (Max.)	3.0046 MPa	4.044MPa	4.122 MPa

Total Deformation (Max.)	3.8005×10^{-5}m	2.3709×10^{-5}m	2.1019×10^{-5}m

The Von Mises stress induced in all three gears are well within the allowable limit (51.57 N/mm^2).

7. Production of CSPE composite spur gear

Spur gears of (module 3 mm, tooth form 20^o involute) are generated from composite cylindrical blanks of 81mm, 96mm and 156 mm diameters each having a thickness of 33 mm, as per the specifications given in Table 6.

Table 6. Specifications of gear blank

Gear No.	Number of Teeth	Gear Blank Diameter (mm)	Base Circle Diameter (mm)	Pitch Circle Diameter (mm)	Shaft Diameter (mm)	Thickness of Gear Blank (mm)
1	50	156	144	150	19	33
2	30	96	84	90	19	33
3	25	81	69	75	19	33

Spur gears are generated using gear hobbing process. Compared to other gear forming processes hobbing is relatively inexpensive and accurate. It is the most widely used gear cutting process for creating spur and helical gears. Figure 6 shows the generation of CSPE composite gear using a hobbing machine and Figure 7 depicts the CSPE composite gears generated.

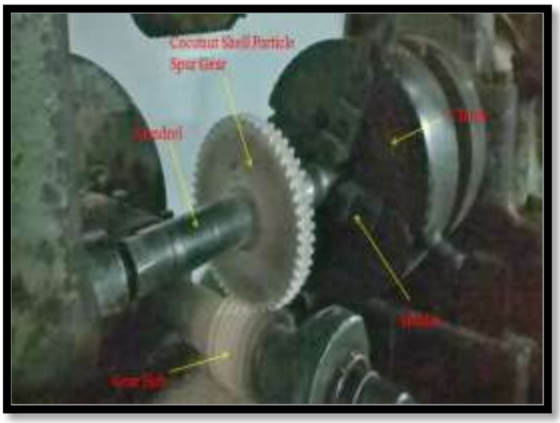
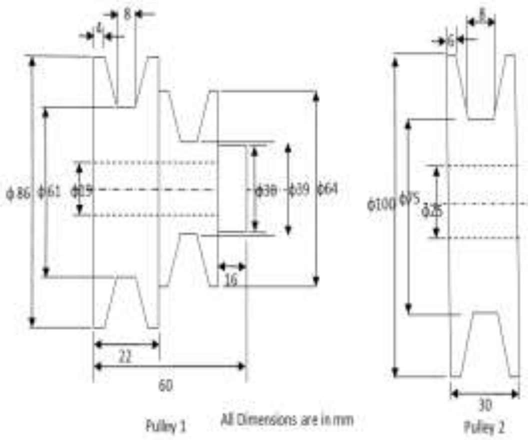


Figure 6. Generation of Gears using gear hob
Figure 7. Generated CSPE composite Gears

An attempt has also been made to fabricate pulleys using CSPE composites for the same machine (Pulleys P1 and P2 in Figure 3) and to conduct performance test by replacing existing metal pulleys. The geometry of the pulley fabricated is shown in Figure 8(a).



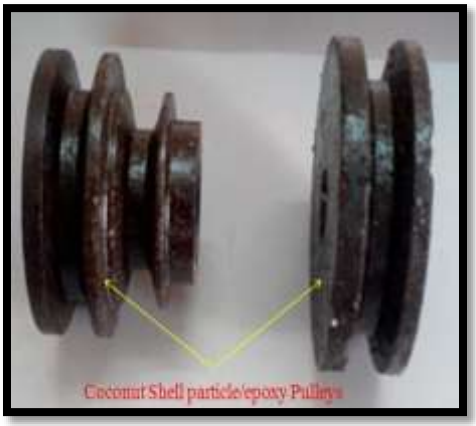


Figure 8(a). Geometry of Pulleys
Figure 8(b). CSPE composite Pulleys

Cylindrical composite pulley blanks for generation of pulleys were fabricated using cylindrical molds of required size in the form of pipes. Pulleys were fabricated by machining these blanks in lathe to the dimensions indicated as in Figure 8(a). Figure 8(b) shows the CSPE composite pulleys machined to the required dimensions.

6. Performance Evaluation of Developed CSPE Composite Gears/Pulleys

The fabricated gears and pulleys from CSPE composite has been tested for their performance by mounting them in a lathe machine. The observations made during their performance in a machine has been discussed.

8.1 CSPE composite gears mounted in PL-4 Lathe

PL-4 Lathe is a medium duty lathe (Kirloskar make) used for performing turning operations on various metallic components of medium sizes at moderate speeds. The specifications of PL-4 Lathe are 0.75kW/1HP power, 440V/3Phase with 1440 rpm speed.

To evaluate the performance of CSPE composite spur gears, the existing steel change gears connected to lead screw of the lathe were replaced with the composite gears (Gear Nos 4, 5 and 6 in Figure 6). Change gears are used to transmit the motion from the stud shaft to the lead screw. Figure 9(a) and 9(b) shows the existing steel and composite gears mounted on the lathe respectively.

(a) Existing steel gears
(b) Replaced composite gears
Figure 9. Change Gear train in Lathe PL-4

Various turning operations has been carried out by changing the speed of the spindle and the performance of the gears were carefully observed. Also, it is observed that the operation is smooth with extremely low noise and vibration and can be used to perform various turning operations at different speeds on both ferrous and non ferrous metals. No damage has been caused to the gear teeth during operation. Since the gears are light weight, are expected to consume less power and no lubrication is necessary.

8.2 CSPE composite pulleys mounted in PL-4 Lathe

To evaluate the performance of CSPE composite pulleys, the existing alloyed steel pulleys connected to motor of the lathe were replaced with the composite pulleys (Pulley Nos 1 and 2 in Figure 3). Turning operations were then carried out on both ferrous and non ferrous metals to check the performance of the composite pulleys. It has been observed that the pulleys performed well with adequate frictional grip with the belt. Figure 10(a) and 10(b) shows the existing steel and composite pulleys mounted on the lathe respectively.

(a) Existing steel Pulleys
(b) Replaced composite Pulleys
Figure 10. Pulleys mounted in Lathe PL-4

8.3 CSPE gears in Parkinson gear tester

Figure 11 shows a pair of CSPE composite gears mounted in Parkinson gear tester.

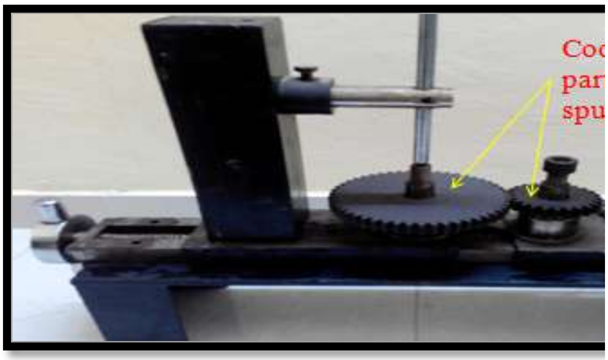


Figure 11. CSPE composite gears mounted in Parkinson gear tester

It has been observed that the gears can be successfully mounted in Parkinson gear tester for measuring the gear tooth profile. The motion can be successfully transmitted between the two gears. However, this unit does not reveal any information about the strength aspects of the gear as no work is done using this unit and hence no force/torque is transmitted between the gears.

Table 7. Comparison between conventional steel gear and CSPE composite gear

Properties	Conventional Steel Gear	CSPE composite Gear	% Difference
Density (kg/m^3)	7800	933	88.04
Weight (N)	39.8	5.03	87.37

The density of CSPE composite is 88.04 % less than that of conventional steel and weight of CSPE composite gear is found to be 87.37% less when compared to conventional steel gear of same size. Low density/light weight CSPE composite gears/pulleys results in high specific strength, with the drastic reduction in the overall weight of the transmission system of machine tools or automobiles.

Conclusion

In this work, spur gears and pulleys were designed and fabricated from CSPE composite and possibility of their use in transmission system of a machine tool has been investigated.

CSPE composite can be easily fabricated using open mould technique with little care to ensure uniform dispersion of filler particles in the matrix during curing.

Coconut shell particles of size 0.25 mm and particle volume fraction of 40 % exhibited better wear and hardness properties which are important for use of material as power transmission elements like gears and pulleys. Hence, the gears and pulleys in the current investigation are fabricated with this composition. CSPE composite is easily machinable and hence, it can be conveniently used in cutting gears and machining of pulleys. Observation of gears during performance test reveal that, no damage has been caused to the gear teeth. This ensures that, the teeth provide adequate strength to withstand the forces generated on gear during turning operation. Observation of pulleys during performance test reveal that, the material of the pulley provide adequate frictional grip with the belt and ensures positive drive.

The material being isotropic in nature, finite element analysis can be carried out easily for any complex geometries. Non-corrosiveness, renewability & biodegradability (coconut shell particles) and low cost are the additional advantages of the material. The material under consideration, being light weight, results in drastic reduction in overall weight of the gear box/transmission system when used in machine tools/automobile. This in turn results in less power consumption in machine tools and improves fuel efficiency in automobiles.

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