



Experimental analysis of reactive stress analysis of polycarbonate spur gears for sugarcane juice machine using FEA

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ABSTRACT

This dissertation work describes design and analysis of Spur gear. Present work, it is proposed to substitute the metallic gear of sugarcane juice machine with plastic gears. Recently, Polyamide 66 and Teflon as plastic materials have been widely used at the manufacturing of gear mechanism. The purpose of the paper is to examine the load capacity of Polycarbonate, Nylon and Cast iron spur gears. In this study, usability of Polycarbonate, Nylon and Cast Iron materials as spur gear was investigated. Gears were analyzed by applying five different loading in ANSYS® 10.0. The Finite Element Method is employed for Plane stress analysis of a Spur Gear tooth model. Analytical methods that are used for getting exact solution of analysis problems. In this work by taking geometrical approximation of a model the plane stress analysis is made to increase the accuracy of a solution and to minimize the solution time. The loading conditions are assumed to be static. As a result of the Analysis, Deformation of Nylon materials was seen rather high. In fact that, Polycarbonate and Nylon materials are Light Weight than Cast Iron materials, the usage of them brings an advantage in many industrial areas. Plastic gears are suitable for the application of sugarcane juice machine under limited load conditions.

Keywords— FEM and ANSYS® 10.0., Polycarbonate spur gears.

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I. Introduction

A Gear can be defined as the mechanical element used for transmitting power and rotary motion from one shaft to another by means of progressive engagement of projections called teeth. Spur Gears use no intermediate link or connector and transmit the motion by direct contact. The two bodies have either a rolling or a sliding motion along the tangent at the point of contact. No motion is possible along the common normal as that will either break the contact or one body will tend to penetrate into the other. Thus, the load application is gradual which results in low impact stresses and reduction in noise. Therefore, the spur gears are used in transmitting power with very less friction losses [1]

Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. It is possible that gears will predominate as the most effective means of transmitting power in future machines due to their high degree of reliability and compactness. In addition, the rapid shift in the industry from heavy industries such as shipbuilding to industries such as automobile manufacture and office automation tools will necessitate a refined application of gear technology. [9] A Sugarcane juice machine as usually used in extracting sugarcane juice which consists of a set of gears, shafts. Their job is to convert the input provided by a prime mover (usually an electric motor) into an output with lower speed and correspondingly higher torque. In this

dissertation, analysis of spur gear in a Sugarcane juice extractor machine was studied using FEM. [10].

1.1 Classification of Gears

- a. Parallel Gears
 - Spur Gear
 - Helical Gear
 - Rack and Pinion
- b. Intersecting Gears
 - Bevel Gear
- c. Non-intersecting and Non parallel Gears
 - Worm Gear

The use of machined plastic gears is increasing in industrial power transmission applications, Cast or extruded gear materials of 50 mm to over 2 meter (2"-84") in diameter are machined to desired dimensions and gear tooth forms. Nylons and acetals are the most widely used thermoplastic gear materials. They offer resiliency, resistance to wear and corrosion, noise reduction, vibration suppression, lightweight and minimum maintenance. [9]

Plastics as gear materials represent an interesting development for gearing because they offer high strength-to-weight ratios ease of manufacture and excellent tribological properties. In particular, there is a sound prospect that plastic gears can be applied for power transmission of up to 10 kW. Typical plastic, such polyamide 66, more commonly known as nylon 66. Have long been known as suitable materials for gearing, it was reported that polyamide gear experienced fatigue failure before significant wear was observed, but crack initiation and propagation mechanisms were unclear. The failure mechanism of polyamide 66 (PA66) gears when run in like pairs are still not clear and, as a result, PA66 users have to substantially underrate their designs for gears. [5]

Plastic gears are serious alternative to traditional metal gears M in a wide variety of applications, The use of plastic gears has expanded from low-power; precision motion transmission into more demanding power trans-mission applications. As designers push the limits of acceptable plastic gear applications, more is learned about the behavior of plastics in gearing and how to take advantage of their unique characteristics. Plastic gears provide a number of advantages over metal gears. They have less weight, lower inertia and are quieter than metal. Plastic gears often require no lubrication or can be compounded with internal lubricants such as PIFE or silicone. Plastic gears usually have a lower unit cost than metal gears and can be designed with part consolidation in mind to incorporate other feature needed in an assembly. These gears are also resistant to many corrosive environments.

The use of thermoplastic materials for gears hampered by a lack of established load carrying and wears performance data, at least when compared to that available for metal gears; nonetheless, there are certain guideline available for estimating the technical feasibility of their use. However, these guidelines have evolved from equations originally worked out for metals and do not take into account some of the unique behavior found in thermoplastic materials. [10]

Weight reduction can be achieved primarily by the introduction of better material, design optimization and

better manufacturing processes. The plastic materials have corrosion resistance, low electrical and thermal conductivity, easily formed into complex shapes, wide choices of appearance, colors and transparencies. The introduction of plastic materials was made it possible to reduce the weight of the spur gear without any reduction on load carrying capacity and stiffness [10].

The Nylon materials have high strength, good mechanical and abrasion resistance property, excellent wear resistance, resistant to most chemicals and self-lubricant. Polycarbonate materials have, high impact strength, good dimension stability and heat resistance. Since, Nylon and Poly carbonate have good properties as stated above the cast iron spur gears of sugarcane juice machine are being replaced by plastic spur gears. The plastic material offer opportunities for substantial weight saving but not always are cost-effective over their cast iron counter parts [10].

Definition of the Problem

In this dissertation work it is proposed to substitute the metallic gear of sugarcane juice machine with plastic gears to reduce the weight and noise. For the purpose of two different types of plastic materials were considered namely Nylon and Polycarbonate and their viability can be checked with their counterpart metallic gear (Cast iron). Based on the static analysis, the best plastic material will be recommended for the purpose. After analysis a comparison is possible among existing Cast iron spur gear. Based on the deflections and stresses from the analysis we can choose the best one between the Nylon and Polycarbonate spur gears

II.LITERATURE SURVEY

The review mainly focuses on replacement of Cast iron spur gears with the plastic spur gear in the application of sugarcane juice machine.

ahesh Badithe et.al. The main aim of this dissertation is to relieve stress from the maximum value to as minimum as possible. So the highest point of contact of teeth is selected as pressure application point which causes highest stress. Stress relieving feature having a shape of aero-fin is used in the path of stress flow which helped to regulate stress flow by redistributing the lines of force. This also yielded better results when compared to elliptical and circular holes. In this study, the best result is obtained by introducing aero-fin hole at (38.7653, 65.4083, 0) and having scaling factor of 0.6. The result displayed a stress reduction by 50.23% and displacement reduction by 45.34% [2] Steve Wasson has shown that Plastic gears are more common than ever, and are now seen in the home, office, automobile and elsewhere. They have gained acceptance due to manufacturing methods such as injection molding, which produces economical, yet very reproducible gears. Noise reduction and corrosion resistance are also reasons why plastic gears are used. Plastic gears are now not only used for light-loaded applications such as printers and toys, but for highly loaded or evaluated temperature environments such as automotive starter gears turbo actuators, electronic throttle control, etc [2]

R. Yakut, et.al. In this study, load carrying capacity and occurring damages of gears which are made of PC/ABS blends were investigated. PC is hard material and ABS is soft material. The usage of materials limits these drawbacks.

However PC and ABS polymers combine each other, the PC/ABS blends have suitable mechanical properties for gear applications in the industrial areas. In this study, usability of PC/ABS composite plastic materials as spur gear was investigated. PC/ABS gears were tested by applying three different loading at two different numbers of revolutions on the FZG experiment set. [7]

T. Shoba Rani et.al. This dissertation gives information about efficiency, as deflections are less the efficiency of nylon spur gear is more than the cast iron spur gear, results in less noise and long life, The metallic gear results is more deflection compared to nylon and polycarbonate, the cost price and life of nylon is also good. When we replace the metallic spur gear with nylon gear there would be better results we can find in the automobile, robotic and in medical fields where the need of nylon gear is there. [9]

Vohra Maheub, et.al. This dissertation gives information about design-optimization methodology to determine the comparative analysis of spur gear with different material for increase the possibility for application of polymer gears. Research and development on different material spur gear shows that if polymer are design-optimized with sufficient care, it can replace most of metallic gears to take additional benefits like low cost, easy manufacturing, low noise-vibration, low maintenance-lubrication.[11]

2.1 Literature about dissertation topic

2.1.1 Sugarcane crusher Heavy duty machine

- Technical Specifications

Cane Crushing capacity/hour 750 - 1000 Kg

Extraction 60 - 65 %

Power requirement 1.5 KW

Speed of Driving Pulley 1400 R.P.M

Size of Pulley 30" X 4. 1/2"

King Roller 8. 5/8" dia. X 8. 1/2"

Crushing Roller 6" dia. X 8. 1/2"

Extracting Roller 6. 1/8" dia. X 8. 1/2"

Net weight 615 Kg

Gross weight 750 Kg

-Geometric details of desired spur gear:

- Module (m) = 10 mm
- Addendum = 1 module
- Dedendum = 1.157module
- Pressure angle (α) = 20 degrees
- Tooth thickness (t) =1.571module
- Whole depth = 2.25 modul

III.THEORETICAL ANALYSIS.

1 Material Properties of Cast Iron, Nylon and Polycarbonate (10)

Table 1 Material Properties of Cast Iron, Nylon and polycarbonate

Material Property	Cast Iron	Nylon	Polycarbonate
Young's Modulus (N/mm ²)	1.65 x 10 ⁵	2.1x 10 ³	2.75 x 10 ³
Poisson's Ratio	0.25	0.39	0.38
Density (Kg/mm ³)	7.2 x 10 ⁶	1.13 x 10 ⁻⁶	1.1x 10 ⁻⁶
Co-efficient of friction	1.1	0.15 - 0.25	0.31

Ultimate Tensile Strength (mpa)	320 - 350	55 - 83	55 - 70
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specific

Specifications of sugarcane juice machine motor

Power (P) = 1.5 kW = 1500watt

Speed (n) = 1400 RPM

Power (P) = 2π n t / 60

1500 = (2π x 1400 t) / 60

Torque (t) = (1500 x 60)/ (2π x 1400)

t = 10.2313 N-m

t = 102313 N-mm

t = P_t x (d/2)

P_t = t/ (d/2)

P_t = 10231/90

P_t = 113.677 N

Where 'Pt' is tangential component that uniformly distributed over the face width of the gear.

Using Lewis equation

Tangential load P_t = m b. σ_b.Y

$$113.677 = 10 \times 54 \times \sigma_b \times 0.1034$$

$$\sigma_b = 113.677 / 0.1034 \times 10 \times 54$$

$$\sigma_b = 2.03 \text{ N/mm}^2$$

$$\begin{aligned} \text{Allowable stress of Cast iron (high grade)} &= \text{Ultimate tensile strength} / 3 \\ &= 320 / 3 \\ &= 106.67 \text{ N/mm}^2 \end{aligned}$$

$$2.03 \text{ N/mm}^2 < 106.67 \text{ N/mm}^2$$

$$\begin{aligned} \text{Allowable stress of Nylon} &= \text{Ultimate tensile strength} / 3 \\ &= 69/3 = 23 \text{ N/mm}^2 \end{aligned}$$

$$2.03 \text{ N/mm}^2 < 23 \text{ N/mm}^2$$

$$\begin{aligned} \text{Allowable stress of Polycarbonate} &= \text{Ultimate tensile strength} / 3 \\ &= 62/3 = 20.67 \text{ N/mm}^2 \end{aligned}$$

$$2.03 \text{ N/mm}^2 < 20.67 \text{ N/mm}^2$$

So the design is safe

Calculations of bending stress and strain at different load

3.1.1 Calculations for Cast Iron Spur Gear

- Bending Stress at Pt =113.677 N

$$P_t = m b. \sigma_b.Y$$

$$113.677 = 10 \times 54 \times \sigma_b \times 0.1034$$

$$\sigma_b = 113.677 / 0.1034 \times 10 \times 54$$

$$\sigma_b = 2.03 \text{ N/mm}^2 \dots \text{bending stress}$$

- Strain at Pt =113.677 N

$$\sigma_b = E \times e$$

$$2.03 = 1.65 \times 10^5 \times e$$

$$e = 1.23 \times 10^{-5} \dots \text{strain}$$

Table2 Theoretical Results of Cast Iron Spur Gear

Sr. No	Load (P _t) N	Bending Stress (σ _b) N/mm ²	Strain
1	113.667	2.03	1.23 x 10 ⁻⁵
2	227.334	4.07	2.46 x 10 ⁻⁵
3	341.001	6.10	3.69 x 10 ⁻⁵
4	454.668	8.14	4.93 x 10 ⁻⁵
5	568.335	10.17	6.16 x 10 ⁻⁵

Table3 Theoretical Results of Nylon Spur Gear

Sr. No	Load (P _i) N	Bending Stress ($\bar{\sigma}_b$) N/mm ²	Strain
1	113.667	2.03	0.96×10^{-3}
2	227.334	4.07	1.93×10^{-3}
3	341.001	6.10	2.90×10^{-3}
4	454.668	8.14	3.87×10^{-3}
5	568.335	10.17	4.84×10^{-3}

Table4 Theoretical Results of Polycarbonate Spur Gear

Sr. No	Load (P _i) N	Bending Stress ($\bar{\sigma}_b$) N/mm ²	Strain
1	113.667	2.03	0.73×10^{-3}
2	227.334	4.07	1.48×10^{-3}
3	341.001	6.10	2.21×10^{-3}
4	454.668	8.14	2.96×10^{-3}
5	568.335	10.17	3.69×10^{-3}

III . COMPUTATIONAL ANALYSIS

4.1 Finite Element Analysis [2]

Present work uses ANSYS® 10.0. for FE analysis of a spur gear. ANSYS® 10.0.is widely used FE analysis software both in academics as well as in industry. Using ANSYS® 10.0 one can perform various tasks of FE analysis and there is huge element library available to meet the user requirements of various type of analysis. There are two different user interfaces available i.e. ANSYS® 10.0 classic and ANSYS® 10.0 workbench. Traditionally, ANSYS® 10.0 classic is choice of analysts but of late ANSYS® 10.0 workbench is becoming popular with analysts. Present work used ANSYS® 10.0 classic version 10.0.

Assumptions used

Analysis is done by considering Plane Stress.

Tooth subjected by UDL, Load applied at Pitch Circle Pr, which induces compressive stresses, is neglected

4.2 Generating Involute profile of a spur gear tooth [8]

Involute profile can be generated in CATIA V5 by

Parametric modeling workbench, but in this work it is developed by traditional drafting method in the CATIA V5 R21. The step by step procedure with CATIA images are given below.

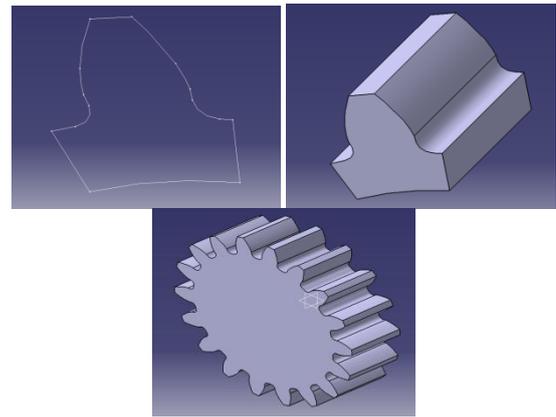
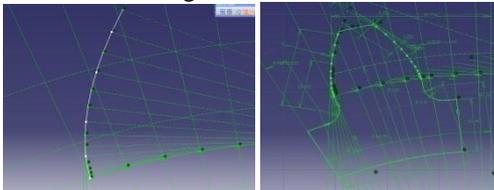


Fig.1 Step by step procedure with CATIA images

4.3 Plane Stress Analysis [9]

It is defined to be a state of stress in which the normal stress $\bar{\sigma}_z$, and the shear stresses $\bar{\sigma}_{xz}$ and $\bar{\sigma}_{yz}$ directed perpendicular to the x-y plane are assumed to be zero. The geometry of the body is essentially that of a plate with one dimension much smaller than the others. The loads are applied uniformly over the thickness of the plate and act in the plane of the plate. The plane stress condition is the simplest form of behavior for continuum structures and represents situations frequently encountered in practice. It is assumed that at any time only one pair of teeth is in contact and takes the total load.

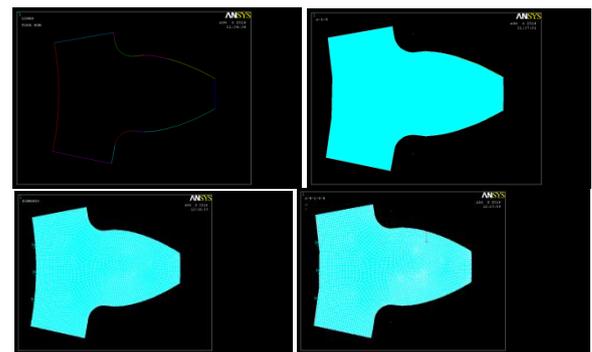


Fig.2 FEA Preprocessor and Processor for Cast Iron Material

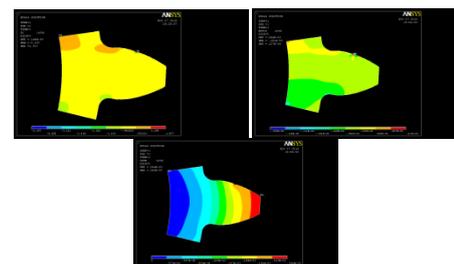


Fig. 3 bending stress, strain and displacement at Pt=113.667 N

Similarly bending stress, strain and displacement at Pt=227.334 N, 341.001N, 454.668N and at 568.335N for Cast Iron, Nylon and Polycarbonate Material obtained Results in ANSYS® 10.0 are as shown below.

Table5 Results of Cast Iron Spur Gear

Sr. No.	Force (N)	Absolute stress N/mm ²	Strain	Displacement
2	227.334	3.874	2.54×10^{-5}	4.92×10^{-4}
3	341.001	5.811	3.80×10^{-5}	7.38×10^{-4}
4	454.668	7.748	$5.07 \times$	9.84×10^{-4}

			10^{-5}	
5	568.335	9.685	6.34×10^{-5}	12.31×10^{-4}

Table 6 Results of Nylon Spur Gear

Sr. No.	Force (N)	Stress N/mm ²	Strain	Displacement
1	113.667	1.937	1.08×10^{-3}	1.68×10^{-2}
2	227.334	3.874	2.17×10^{-3}	3.36×10^{-2}
3	341.001	5.811	3.25×10^{-3}	5.04×10^{-2}
4	454.668	7.748	4.33×10^{-3}	6.73×10^{-2}
5	568.335	9.685	5.42×10^{-3}	8.41×10^{-2}

Table 7 Results of Polycarbonate Spur Gear

Sr. No.	Force (N)	Stress N/mm ²	Strain	Displacement
1	113.667	1.937	0.81×10^{-3}	1.29×10^{-2}
2	227.334	3.874	1.64×10^{-3}	2.58×10^{-2}
3	341.001	5.811	2.45×10^{-3}	3.86×10^{-2}
4	454.668	7.748	3.27×10^{-3}	5.15×10^{-2}
5	568.335	9.685	4.09×10^{-3}	6.44×10^{-2}

V. RESULTS AND DISCUSSION

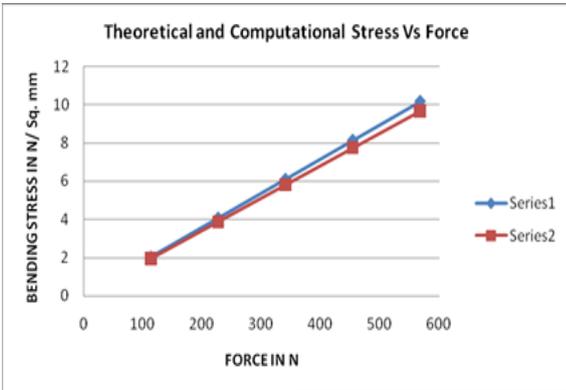


Fig.4 Theory and Ansys Stress Vs Force

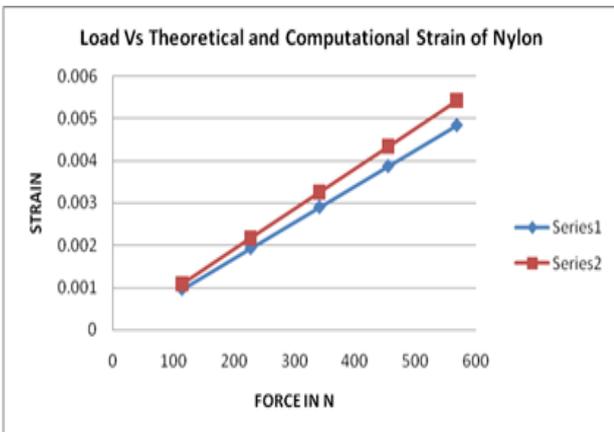


Fig.5 Theory and Ansys Strain Vs Force Cast Iron

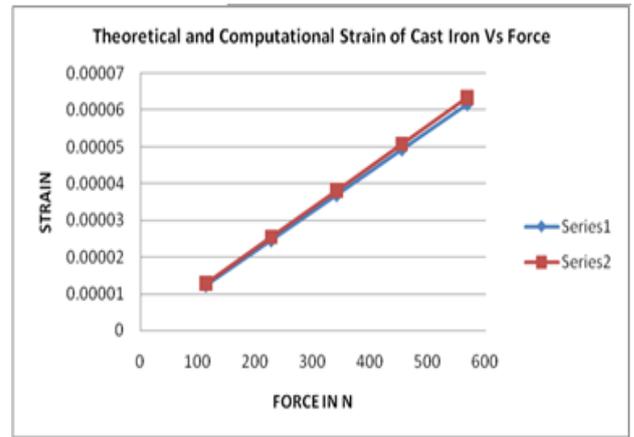


Fig.6 Theory and Ansys Strain Vs Force Nylon

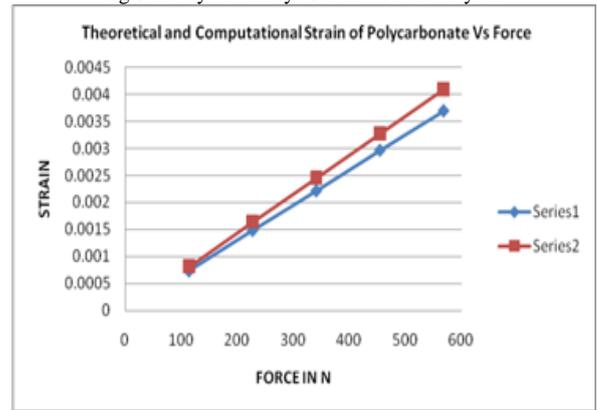


Fig.7 Theory and Ansys Stress Vs Force Polycarbonate

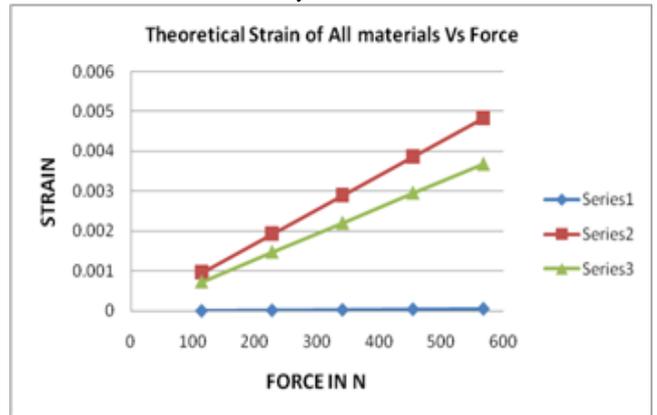


Fig.8 Theory Strain of all material Vs Force Cast Iron

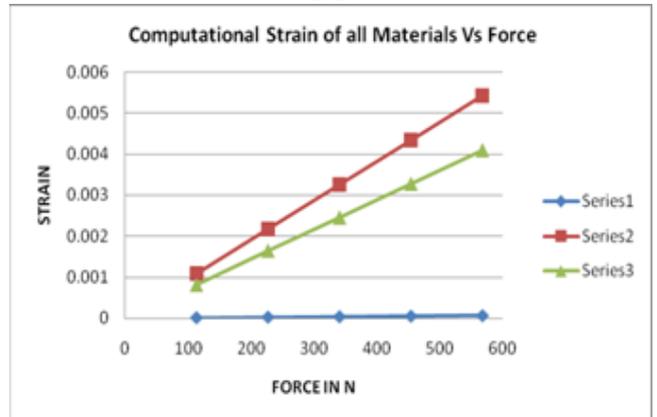


Fig.9 Ansys Strain of All Material Vs Force Nylon

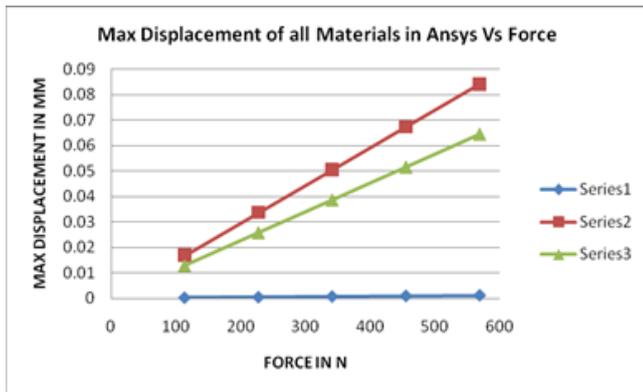


Fig.10 Displacement of All Material Vs Force

5.2 Discussion

From the static analysis by increasing the force on the tooth edge it was observed that the bending stresses and strain values of the spur gear were increased. Induced bending stress values were below the ultimate stress of Polycarbonate and Nylon spur gear, so safe design is possible. Also it was observed that density of Polycarbonate and Nylon material is less than the Cast Iron material. Minimum strain values were obtained for Polycarbonate spur gear compared with Nylon. Also it was observed that minimum displacement value was obtained for Polycarbonate spur gear compared with Nylon. According to the study, analysis and results we recommend the best plastic material is Polycarbonate and Polycarbonate Spur gears are suitable to safe and light weight design for the application of sugar cane juice machine under limited load conditions.

VI. 6 CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusions

- The investigation result infers that there is a difference in a result of theoretical bending stress calculation and computational bending stress calculation (Error 4.58% – 4.81%).
- Bending stress developed in a spur gear tooth subjected to a fixed load is independent of material properties.
- It was observed that Strain and displacement of Gear tooth depends on material property E (Young's Modulus).
- Minimum bending strain values were obtained for Cast Iron spur gear compared with Polycarbonate and Nylon. (At the load of 113.667N the strain value was obtained in Cast Iron gear tooth 1.23×10^{-5} by theoretical Analysis, However at same load strain values were obtained in Polycarbonate and Nylon 0.73×10^{-3} , 0.96×10^{-3} respectively)
- It was observed that density of Polycarbonate and Nylon is less than Cast Iron material. So the Polycarbonate and Nylon materials are light weight Compare to Cast Iron
- It was observed that displacement value of Polycarbonate material is less than Nylon material.
- Induced stress was below the Maximum Allowable stress observed in Polycarbonate and Nylon material at same load. (At the force of 113.667N, Induced stress obtained in Nylon and Polycarbonate material was 2.03 N/mm^2 and 2.03 N/mm^2).
- According to study, analysis and results we recommend the best plastic material is Polycarbonate for safe and light weight design. Polycarbonate spur gears are suitable for the

application of sugarcane juice machine under limited load conditions.

6.2 Scope for further work

GEARS OF ANY MATERIAL HAVING CIRCULAR ROOT FILLET DESIGN CAN BE INVESTIGATED USING SIMILAR PROCEDURE. IT IS IMPORTANT BECAUSE IT IS OBSERVED THAT USE OF CIRCULAR ROOT FILLET INCREASES THE BEAM STRENGTH OF GEAR TOOTH AS COMPARE TO THAT IN CASE OF TROCHOIDAL ROOT FILLET.

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