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Research Article

Carbon Fiber Sprocket: Finite Element Analysis and Experimental Validation

Nikhil P. Ambole [†*] **and Pravin R. Kale**[†]

[†]Department of Mechanical Engineering, JSPM's, RSSOER, Narhe, Pune University, Pune-41, India.

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Abstract

The sprocket is a very essential part in the transmission of power and motion in most motorcycles. Generally sprockets are made of mild steel. In this paper, existing sprocket motorcycle is compared with the sprocket of carbon fiber material. The drawing and drafting is done using CAD software. Further FEA software is used for analysis of sprocket chain. With different properties of mild steel and carbon fiber, stress and deformation of sprocket is compared. This work will be useful for further development of sprockets chain.

Keywords: *CAD, Carbon fiber, FEA, Mild steel, Sprocket, Stress and deformation.*

1. Introduction

Roller chain or bush roller chain is one of the type of chain drive mostly used for transmission of mechanical power on many kinds of domestic, industrial, agricultural machineries, as well as includes conveyor, tube-drawing machines, printing presses, cars, motorcycles, and bicycles etc. Chain drive consists of a series of short cylindrical rollers held to get herby side links as shown in fig.1. Chain drive is driven by a toothed wheel called a sprocket.

Fig. 1 Photograph of sprocket chain of Bajaj Pulsar 180

Now a day most of the motorbikes have conventional chain drive by which power is transmitted from engine to rear wheel. Chain drive consists of two main parts, one is chain and other is sprocket. Mostly chain and sprocket are made of mild steel material. As we know steel is corrosive and has less life and also has more weight. To overcome these and other problems there should be replacement for steel. Chain sprocket has problems like braking of bushings and/or rollers, braking of plates and pins (unusual cracks), quickly wear of sprockets, Worn rollers, etc. Possible causes of this problem are significant overload breakage, high impact pressure, excessive chain wear far beyond replacement level, combination of worn chain with new sprockets etc.

The sprocket chain when used for long term faces problems such as pins or bushes wear out, broken plates and pins, wearing of sprocket etc. also chain sprockets works in very dirty environment which lowers its life. Normally sprocket chain is made up of alloy steel. So the objectives of this study are,

1) To increase strength of a sprocket so that it can be used for long time.
2) To reduce the weight of sprocket.
3) To select an alternative material for the sprocket.
4) To analyses the sprocket with existing as well as alternating material.
5) To validate the results for better output.

For this research, many international and national papers were helpful. Worldwide researchers have applied the efforts of design sprocket chain as,

Ebhota Williams S, *et al.*, (2014), studied the fundamentals of sprocket design and manufacturing of a rear sprocket of Yamaha CY80 motorcycle through reverse engineering approach. The eight steps that are to be followed sequentially in the reverse engineering approach are discussed. They manufactured the sprocket by universal milling machine from the blanked mild carbon steel (AISI 1045) with chemical

*Corresponding author: **Nikhil P. Ambole**

composition of C=0.45%, Mn=0.75%, P=0.03% max, S=0.04%. Then induction heat treatment was applied to move the material hardness from 13 HRC to 45 HRC.

Swapnil Ghodake *et al*., (2013), Sprocket weight optimization is done with reducing material to get optimized design which can perform well under torque condition keeping same constraints. For this purpose, an FEM tool is used for analysing existing and optimized sprocket with different types of FEA techniques. Strain Gauging is done or correlation with FEA virtual strain to confirm the loadings. Conceptual Test rig is proposed to validate the optimized sprocket. Chandraraj Singh Baghel, *et al*., (2013), studied of the stress of chain; sprocket of motorcycle is compared with the sprocket of plastic material made by PEEK (polyether ether ketone). Chaitanya G Rothe *et al*., (2015), deals with the replacement of conventional steel drive shaft with high strength carbon/epoxy composite drive shaft. The design parameters were optimized with the help of genetic algorithm (GA) with the objective of minimizing the weight of composite drive shaft. The result of GA are used for modelling of carbon/epoxy composite drive shaft and steel drive shaft using CAD software to perform static, buckling and modal analysis of both drive shaft using ANSYS.

No researcher has applied effort for designing of sprocket with carbon fiber. Therefore, there is stern need to work on sprocket with composite material. In this work, we introduced the carbon fiber as replacement for conventional mild steel. Also we done the CAD through reverse engineering and analysis is carried out using Hypermesh and ANSYS.

2. CAD through Reverse Engineering

Dimensions are required for calculating of boundary conditions. Hence it’s CAD (Computer-aided design) model is necessary. The conventional sprocket model of Bajaj Pulsar 180is used. Input for design of sprocket is taken from rear wheel sprocket of Bajaj pulsar 180. CAD model then is made by the commands in CATIAV5 R19 of pad, pocket, fillet, and geometrical selections in part design module. Parametric generation of drawings will help to get the dimensions useful in forces calculations in static loading conditions on a component.

Standard procedure for designing and drawing the sprocket:

This process provides a method for generating solid models of any standard sprocket, given the pitch, number of teeth, sprocket thickness etc. by first sketching the profile of the sprocket as given in fig 2.

Input → Bajaj Pulsar 180 rear wheel sprocket

1. Number of teeth= 42
2. Roller diameter = 8.51mm
3. Sprocket thickness = 7.2
4. Chain pitch =12.7mm
5. Sprocket diameter = 170mm

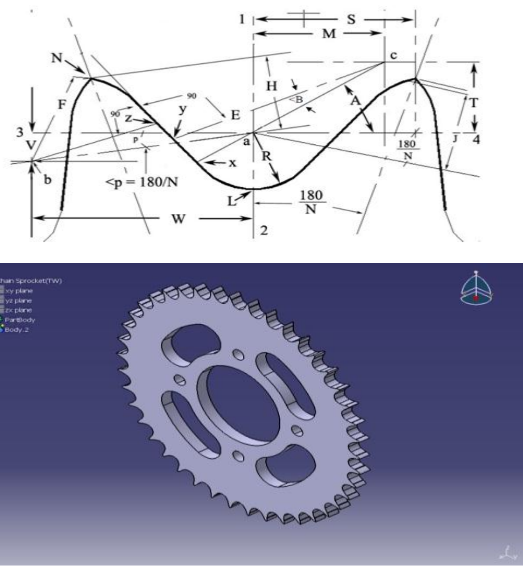


Fig.2 CAD modelling of sprocket

3. Materials for Sprocket

The selection of material used for the manufacturing of sprocket depends upon the strength and service conditions like wear and noise etc. also involves the cost as well as the material performance required. The sprockets may be manufactured from metallic or non-metallic materials. The steel is widely used for the manufacturing of sprocket due to its good wearing properties, excellent machinability and ease of producing complicated shapes by machining. Sprockets can also be supplied in various cast materials as Standard Carbon Steel (with or without hardened teeth), Stainless Steel, Special materials such as alloy steel, bronze etc. The non-metallic materials like wood, compressed paper and plastics like Nylon, Acrylic and Polycarbonate etc. are used for gears, especially for reducing weight and noise.

3.1 Mild Steel (IS 2062)

At present sprocket chain is made of mild steel material. So, first analysis is done using MS as material. Steel is the traditional material for sprocket chain. Steel is easy to get. Machinery to manipulate steel is easy to get. Steel is easy - and it's also cheap. This is the main reason that 99% of the sprocket chain are made from steel. Steel is stiff but dense (heavy). Steel rates well in terms of both yield strength and ultimate strength, particularly if it's carefully alloyed and processed. Steel also resists fatigue failure well which is extremely useful - even if the sprocket chain flexes under load, such flexing need not lead to a critical failure.

Chemical Composition of IS 2062:

C- 0.23% , Mn-1.5%, S-0.05%, P-0.05%, Si-0.4%

The properties of mild steel are listed below, Structural Properties (IS 2062):

Table 1 Material properties of steel

Property	Value
Young's Modulus, E	2.1x10^5 MPa
Poisson's Ratio ,ν	0.3
Density, ρ	7850 kg/m^3
Yield Stress, σ_{yield}	250 MPa
Ultimate Tensile Stress, σ_{uts}	390 MPa

3.2 Carbon Fibers

Carbon fibers, more than all other fibrous reinforcements, have provided the basis for the development of advanced structural engineering materials. Commercially carbon fibers are available with a variety of tensile moduli ranges from 207Gpa to 1035 GPa respectively low to high side. In general, low modulus fibers have low cost, low specific gravities, high tensile and compressive strengths and high tensile strain to failure than high modulus fibers. The benefits of carbon fibers are their extraordinarily higher tensile strength to weight ratios and tensile modulus to weight ratios, very lower CTEs (which provide dimensional stability in such applications as space antennas) and higher fatigue strengths. The disadvantages are their low impact resistance and high electric conductivity, which may cause shorting in unguarded electrical machinery. Their high cost has so far excluded them from widespread commercial use. Carbon fibers are extensively used in aerospace and some applications of sporting goods, taking advantages of the relatively high stiffness to weight and high strength to weight ratios of these fibers. The structure and properties of carbon fibers are depends on the raw material used and the process circumstances of manufacture. Carbon fibers commercially exist in three simple forms, namely, long, continue tow, chopped (6-50mm long) and milled (30-3000μm long). The long, continues tow, which is simply a bundle of 1000-160.000 parallel filaments, is used to for high performance applications.

Characteristics of carbon fiber:

1) High strength to weight ratio
2) Rigidity
3) Corrosion resistance and chemically stable
4) Fatigue resistance is good
5) Good tensile strength
6) Fire resistance/ Non flammable
7) Low coefficient of thermal expansion
8) Self-lubricating
9) High damping

Material properties for carbon fiber:

Table 2 Material properties of carbon fibers

Mechanical Properties	Units	Carbon Fiber
E_{11}	GPa	190
E_{22}	GPa	7.7
G_{12}	GPa	4.2
ν_{12}		0.3
P	Kg / m^3	1600
$S^t_1 = S^c_1$	MPa	870
$S^t_2 = S^c_2$	MPa	54
S_{12}	MPa	30

4. Finite Element Method (FEM)

Analysis is done by selecting appropriate solver and carrying out the processes in various stages to get solution. Particularly analysis is carried out in three stages by performing various operations in software.

4.1. Pre-processing

A) Meshing

In this stage IGS file is imported to the meshing software like Hypermesh 12.0. The CAD data of the Sprocket chain is imported and the surfaces were created and meshed. Since all the dimensions of the sprocket are measurable, the best element for meshing is the tetra-hedral element. Here, static analysis is used for analysis. Fig. 3 shows the meshed model of sprocket in Hypermesh. For this following parameters are used.

No. of Nodes: 16552
No. of Elements: 62272
Element size: 2mm

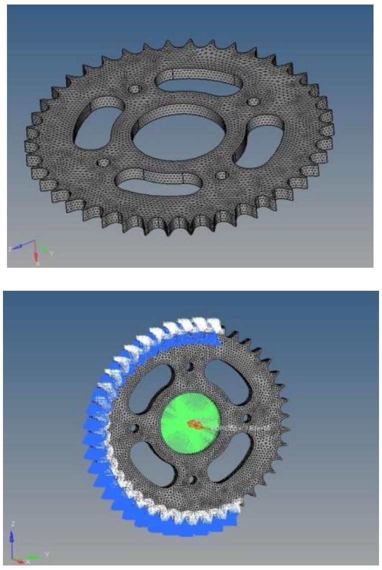


Fig. 3 Meshing and boundary condition

B) Boundary Conditions

After meshing is finished we apply boundary conditions. These boundary conditions are the reference points for calculating the results of analysis.

Forces acting on sprocket:

1) Force acting on sprocket due to tension in tight side of chain (Torque at rear sprocket)
2) Gravitational force acting at the centre of sprocket (in this case neglected)

Calculation for Torque at rear sprocket (Pulsar 180):
Gear ratio = 26.93:1
Engine torque = 14.22 Nm @ 6500 rpm
∴ Torque at rear sprocket = Te X G
= 14.22 X 26.93
= 383 Nm

Below fig. 4.2 shows loads and constraints applied in hypermesh. Sprocket has been constraint at the circumference and torque of 383 Nm is applied at the center.

4.2 Solution and Post-processing

Meshed and boundary condition applied model is imported to the solver. Analysis process starts after applying run in the solver software. Software first calculates the deflection with respect to the boundary conditions applied. Then on the basis of deflection it computes strain. Once the strain is calculated we know modulus of elasticity then we can compute the stress values. Results are viewed and accordingly modifications are suggested. Changes are suggested according to high stress regions obtained. If the stresses are beyond the permissible limits then changes such as change in material, change in thickness of component or addition of ribs etc. are made according to suitability. The calculation of stress depends upon the failure theory suitable for the analysis.

1) Following are the results displayed for stress and deformation (MS)

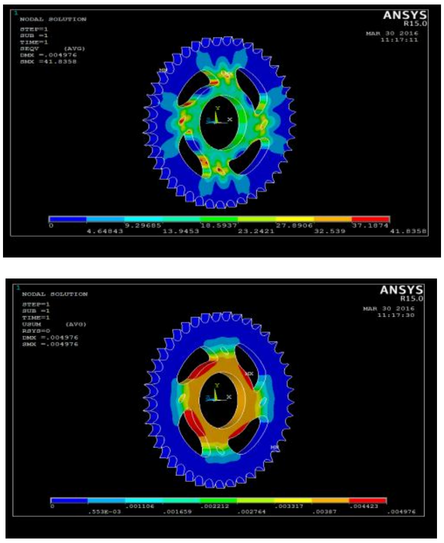


Fig. 4 Results displayed for stress and deformation (MS)

Fig. 4 shows the analysis results obtained in ANSYS for sprocket with mild steel. Stress value for sprocket chain is 41.83 N/mm2 which is well below the critical value. Hence, design is safe. Deformation for sprocket chain is 0.0049 mm.

2) Following are the results displayed for stress and deformation(Carbon Fiber)

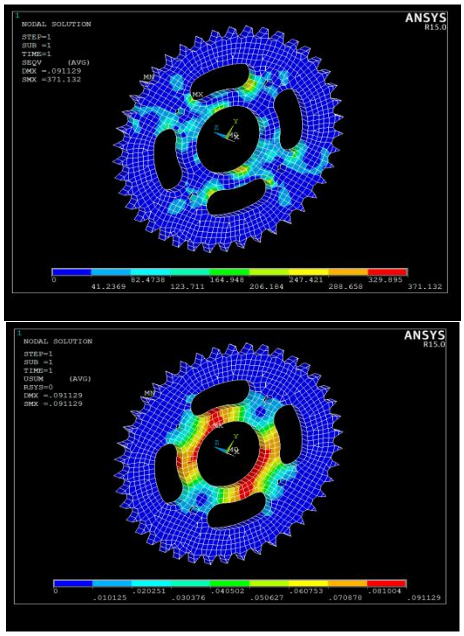


Fig. 5 Results displayed for stress and deformation (Carbon Fiber)

Fig. 5 shows the analysis results obtained in ANSYS for sprocket with carbon fiber. Stress value for sprocket is 371.13 N/mm2 which is well below the critical value. Hence, design is safe. Deformation for sprocket is 0.091 mm.

The analysis of sprocket has been done for all two materials viz. steel, carbon fiber. The comparison of properties and analysis results is shown in table A and B respectively.

Table 3 Comparison of material properties

Material	Mild Steel	Carbon Fiber
Young's Modulus (E)	210 GPa	E1-190 GPa E2-7.7 Gpa
Poisson's Ratio (υ)	0.3	0.35
Density (ρ)	7850 kg/m^3	1600 kg/m^3
Yield Stress (σ_{yield})	290 MPa	-
Ultimate Tensile Stress (σ_{uts})	390 MPa	2000 MPa
Mass (m)	0.847 Kg	0.173 Kg

Table 4 Comparison of analysis results

S. No.	Material	Max. Stress	Max. Displacement
1.	Steel	41.83 MPa	0.0049 mm
2.	Carbon Fiber	371.13 MPa	0.091 mm

5. Method of Fabrication

5.1 Preparation of carbon fibre prototype by hand lay-up method

Hand lay-up is a simple method for composite production. A mould must be used for hand lay-up parts. Reinforcement fibers can be cut and laid in the mould. Resin must then be catalyzed and added to the fibers. A brush, roller or squeegee can be used to impregnate the fibers with the resin.

Material Used:
1) Epoxy resin: Epoxy laminating resin boasts higher adhesive properties and resistance to water
Chemical name - Diglycidyl ether of biphenyl
Company name - Araldite- LY556
2) Catalyst Hardener: Organic peroxide or similar compound which, together with the accelerator, initiates the polymerization process of polyester and other resins.
Chemical name- Triethylene tetramine.
Company name- Aradur-HY951.
3) Accelerator: One of the two compounds (the other is catalyst) required to initiate the polymerization process.

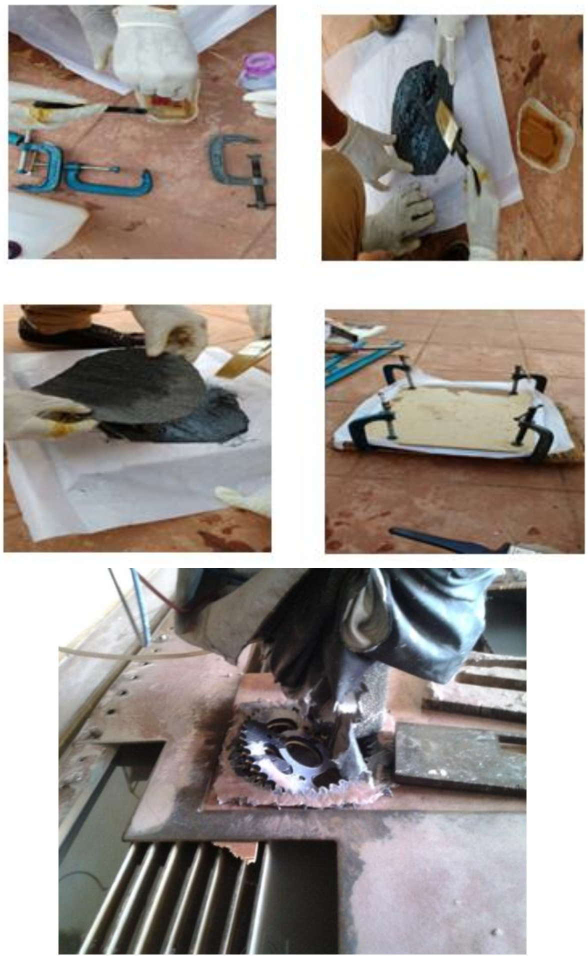


Fig. 6 Laminate manufacturing anf profiling of Carbon Fiber Sprocket

5.2 Profiling of sprocket using waterjet machine

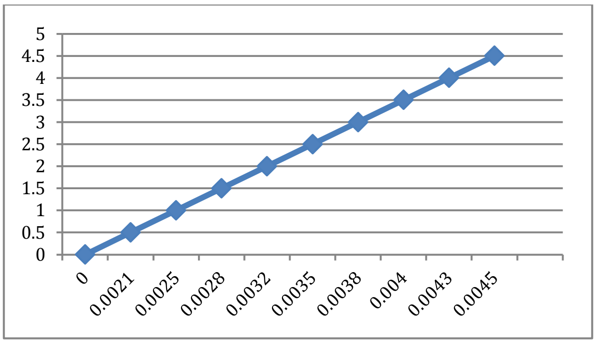
All water jets follow the same principle of using high pressure water focused into a beam by a nozzle. Most machines accomplish this by first running the water through a high pressure pump. There are two types of pumps used to create this high pressure; an intensifier pump and a direct drive or crankshaft pump. A direct drive pump works much like a car engine, forcing water through high pressure tubing using plungers attached to a crankshaft. An intensifier pump creates pressure by using hydraulic oil to move a piston forcing the water through a tiny hole. The water then travels along the high pressure tubing to the nozzle of the waterjet. In the nozzle, the water is focused into a thin beam by a jewel orifice. This beam of water is ejected from the nozzle, cutting through the material by spraying it with the jet of high-speed water. The process is the same for abrasive waterjets until the water reaches the nozzle. Here abrasives such as garnet and aluminium oxide, are fed into the nozzle via an abrasive inlet. The abrasive then mixes with the water in a mixing tube and is forced out the end at high pressure.

6. Experimentation

Furthermost part, so we want to validate the FEA analysis with the Experimental analysis. So both steel and carbon fiber sprocket tested were on UTM for experimental results as shown in fig 7.

Fig. 7 Experimental setup and Test specimen

Here are experimental results are shown in fig.8 which is load vs deformation for steel.



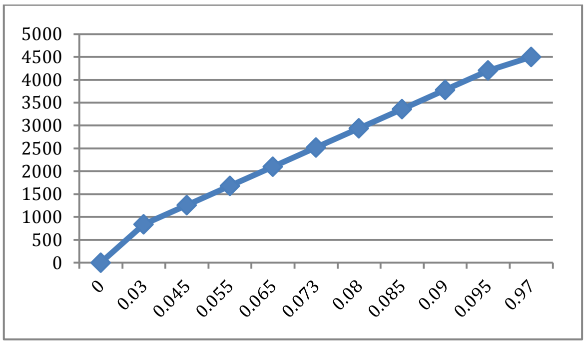


Fig. 8 Experimental results: **-** a) Mild Steel b) Carbon Fiber

The experimental result is 0.0045 m for 4.5 KN but we have the FEA results and compare with experimental result. The maximum deformation found was 0.097 at load of 4.5 KN but we have to compare the FEA results and with experimental result.

Table 5 Comparison between Experimental and FEA results

	Deformation (mm)		Mass (Kg)	
	Mild Steel	Carbon Fiber	Mild Steel	Carbon Fiber
FEA Results	0.0049	0.091	0.847	0.173
Experimental Results	0.0045	0.097	0.850	0.210
Percentage Error	8.10 %	6.18 %	0.35 %	17.61

Conclusions

From results of finite element analysis it is observed that stresses are maximum at joint locations. It is also observed that both the materials have stress values less than their respective permissible yield stress values. Hence the design is safe. From analysis results and comparison of properties of all the materials, it is found that carbon fiber is the material which is having the least density; also it is easily available and cheap as compared to other alternate materials. Also machining cost for carbon fiber is less. Mass of carbon fiber sprocket is reduced by 75.29% comparative to mild steel sprocket. Hence carbon fiber is the best suited alternate material for sprocket and is expected to perform better with satisfying amount of weight reduction.

References

Ebhota Williams S, Ademola Emmanuel, Oghenekaro Peter, (2014), Fundamentals of Sprocket Design and Reverse Engineering of Rear Sprocket of a Yamaha CY80 Motorcycle, *International Journal of Engineering and Technology*, 4, pp. 170- 179.

Swapnil Ghodake, Prashant Deshpande, Shrikant Phadatare, (2014), Optimization of Excavator Sprocket and its Validation by Test Rig Concept, *Conference on Advances in Engineering and Technology*, pp. 253-256.

Chandraraj Singh Baghel, Abhishek Jain, Dr. A.K. Nema and Anil Mahapatra, (2013), Software ANSYS Based Analysis on Replacement of Material of Sprocket Metal to Plastic Material PEEK, *International Research Journal of Engineering and Applied Science*, 1 (4).

Chaitanya G Rothe, A. S. Bombatkar , (2015), Design and Analysis of Composite Material Drive Shaft, *International Journal of Innovative and Emerging Research in Engineering*, 2 (1), pp. 72-84.

R. V. Mulik, Prof. M. M. Joshi, Dr. S. Y. Gajjal, S. S. Ramdasi and N. V. Marathe, (2014), Dynamic Analysis of Timing Chain System of a High Speed Three Cylinder Diesel Engine, *International Journal of Engineering and Science,* 4 (5), pp. 21-25.

Candida Pereira, Jorge Ambrosia, Amilcar Ramalho, (2010), Contact Mechanics In A Roller Chain Drive Using A Multibody Approach, *11th Pan-American Congress of Applied Mechanics Copyright © 2009 by ABCM* January 04-08.

Sine Leergaard Pedersen, (2014), Simulation and Analysis of Roller Chain Drive Systems, *PHD Dissertation, technical university of Denmark.*

C Conwell, (1989), An Examination of Transient Forces in Roller Chain Drives, *Ph.D. Dissertation: Vanderbilt University, Nashville, TN.*

V. V. R. Murthy, T. Seetharam, V.Prudhvi Raj, (2015), Fabrication and Analysis of Sprocket Side Stand Retrieval Systems, *International Journal & Magazine of Engineering, Technology, Management and Research*, 2 (7), pp. 211-215.

Tushar D. Bhoite, Prashant M. Pawar & Bhaskar D. Gaikwad, (2012), FEA Based Study of Effect of Radial Variation of Outer Link in A Typical Roller Chain Link Assembly, *International Journal of Mechanical and Industrial Engineering,* 1 (4), pp.65-70.

Karim H. Shalaby, Simona Lache, and Florin Corciova, (2016), Contact Forces Analysis of an Analogous Huygens Pendulum Using Inverted Tooth Chain, *International Journal of Materials, Mechanics and Manufacturing,* 4 (3), pp.195-199.

A. Arriaga, J. M. Lazkano,R. Pagaldai ,A.M. Zaldua,R. Hernandez, (2013), Finite-element analysis of quasi-static characterisation tests in thermoplastic materials: Experimental and numerical analysis results correlation with ANSYS, *International Journal of Mechanical and Industrial Engineering,* 2 (3), pp. 223 –647.

Pintoo Prajapati, Vipul kr. Srivastav, Rahul kr. Yadav, (May June 2015), Sprocket side stand retrieve system, *International Journal of Technical and Application*, 3 (3), pp. 86-87.

Amol J. Kadam, (2015), Design and analysis of conveyor chain link using composite material: a review, *IJIERT, pp. 1-6.*

P. K. Harish Kumar, B. K Kanimozhi, (2014), Design analysis and application of Nylon66 in rotary spars, *International Research Journal of Engineering Research and Applications*, 4 (4), pp. 331-334.

http://www.zeusinc.com/newsletter

http://en.wikipedia.org/wiki

http://www.gearseds.com

https://mdmetric.com/tech/chempropi.htm