



DESIGN AND STATICAL STRUCTURAL ANALYSIS OF CONNECTING ROD USING DIFFERENT MATERIAL

* Pulkit Kumar¹, Prabhakar², Arvind Kr Paswan³

¹M. Tech scholar, Department of Mechanical Engineering, B.I.T Sindri, Dhanbad, India

²Assistant Professor, Department of Mechanical Engineering, B.I.T Sindri, Dhanbad, India

³M Tech Scholar, Department of Mechanical Engineering, B.I.T Sindri, Dhanbad, India

Abstract - The connecting rod serves as the intermediate member/element or bridge between crankshaft and the piston. Transmitting pull and push from the piston pin to the crank pin is the main and primary function of connecting rod, thus converting the reciprocating motion of the piston into rotary motion of the crank. The two types of connecting rod failure that occur most frequently are tensile failure from high engine speeds and casting defect from cyclic load behavior. In order to increase performance metrics while lowering component weight, this research attempts to substitute the traditional material used to make connecting rods, such as steel. This study compares a connecting rod made of steel, a conventional material, with those constructed of carbon fibre, copper alloy, grey cast iron, zinc pure, aluminium alloy, and titanium alloy. The connecting rods are of standard dimensions. Based on the Strength and Stiffness Criteria, the Shape and Materials have been chosen. In order to forecast the model's structural strength and buckling limit, the project also used finite element method on a commercial piece of software called ANSYS Workbench to analyze static structural characteristics including Von-Mises Stress, strain, Deformation, Factor of Safety, and Buckling Analysis of conventional connecting rod designs.

Key Words: Connecting rod, Ansys Workbench, Finite Element Analysis, Aluminium alloy, Carbon fiber, Titanium alloy, Steel, Design and Analysis

1 INTRODUCTION

- Between the piston and the crankshaft, the connecting rod serves as an intermediary element. Its main job or the primary function is to change the piston's reciprocating motion or thrust into the crank's rotating motion by transmitting push and pull from the piston pin to the crank pin.
- The connecting rod plays a pivotal role in transforming the back-and-forth motion of the piston into the rotational motion of the crankshaft, facilitating the movement of the vehicle. This conversion process subjects the connecting rod to various types of loads and stresses, including bending, tension, compression, and the potential for buckling. At its larger end, the connecting rod is linked to the crankshaft via a plain bearing and crank pin, while at its smaller end, it connects to the piston through a piston pin.
- In modern automotive internal combustion engines (IC), connecting rods are predominantly constructed from steel for standard production engines. However, for specific purposes, alternative materials come into play. Aluminum is used to reduce weight and enhance the capacity to absorb high impacts, although this comes at the cost of durability. Titanium is employed for engines of high performance, as it offers a compelling blend of strength and lightweight properties, albeit at a higher price point. In certain applications, like motor scooters and bikes, cast iron is utilized for its specific characteristics.
- The connecting rod within an internal combustion (IC) engine operates under constant high stress, making it particularly susceptible to failure under adverse conditions. An ideal connecting rod must strike a balance between being lightweight and cost-effective while possessing the necessary strength to endure the substantial stresses and high-cycle fatigue it experiences. Recent research has shifted the

focus from materials with uniform compositions to a diverse range of metal alloys and composite materials. These advancements aim to enhance performance, increase strength and stiffness, reduce weight, improve wear and corrosion resistance, and mitigate thermal expansion. Materials like Metal Matrix Composites (MMCs), Aluminum-Silicon Carbide Composites, and several metal alloys have emerged as promising solutions for applications that demand a combination of strength, thermal conductivity, a low coefficient of thermal expansion, and reduced density. Such innovations contribute to lighter connecting rods, ultimately enhancing engine efficiency.

- The connecting rod endures immense stress due to the reciprocating Load generated by the action of piston, constantly stretching and compressing as the engine rotates. This load amplifies significantly as the engine speed increases, rising to the power of three.
- The failure of the connecting rod, commonly known as "throwing a rod," ranks among the leading causes of catastrophic engine breakdown in automobiles. This often results in the fractured rod piercing through the crankcase, rendering the engine irreparable.



Fig. 1 Connecting rod

2 LITERATURE REVIEW

This section focuses on the literature papers that were reviewed as part of our project to gain a deeper understanding of the

material selection criteria for connecting rods.

1. Pandiyan and colleagues, et al. [1], analyzed the use of Aluminium alloys and composites for connecting rods. Their research highlighted that materials of this nature exhibit high hardness, strength, and durability. They found that using A1 6061-T6 material for the connecting rod reduced weight by 7.98% compared to ADC12, while maintaining the strength-to-weight ratio and ductility. This conclusion was drawn through the application of topology optimization methodology.
2. Shubham Tiwari and his team, et al. [2], focused on optimizing the shape, manufacturing process, and suitable alloys and composites for connecting rods. They explored Powder Metallurgy, which improved the microstructure and mechanical properties of the connecting rod. Their study suggested that using Titanium Alloy instead of steel significantly enhanced tensile elongation and tensile strength.
3. Vikas Singh and colleagues et al. [3], used ANSYS software for force, stress, and strain analysis of various materials for connecting rods. By applying boundary conditions and employing finite element analysis, they determined deformation, strain, and stress values for different materials.
4. Somnath Chattopadhyay et al. [4], conducted fundamental calculations to aid in material selection and provided insights into suitable manufacturing processes for different materials.
5. Research by Adnan Ali Haider and team, et al. [5], concluded that Titanium Alloy was the most suitable material for manufacturing connecting rods due to its superior Factor of Safety and minimal deformation. Aluminium Alloy 7075-T6 was the second-best choice, with lower Factor of Safety but a significantly reduced weight compared to Titanium Alloy.
6. Kuldeep B, et al. [6], explored the assembly of connecting rods with carbon steel, noting that modern practices favor aluminum alloys. They conducted a study involving aluminum-based composite materials reinforced with silicon carbide and fly ash. Finite element analysis revealed stress, strain, and displacement parameters using ANSYS software.
7. Ashby, M. F., et al. [7], investigated the reforming of steel connecting rods and outlined three production processes: die casting, forging and machining, and powder methods with machining. Their findings indicated that, for a production volume of ten thousand components, forging was the most cost-effective, followed by die casting. Powder methods were relatively more expensive due to slower production and capital costs.
8. Mr. H D. Nitturkar, et al. [8] observed that minimum stress occurred at the crank and piston ends under all loading conditions. This led to a reduction in material at these locations, resulting in cost savings.
9. Pravardhan S. Shenoy, et al. [9], introduced a finite element analysis procedure to reduce the weight and cost of connecting rods. Their study involved connecting rods made of forged steel, and through an iterative process, they successfully reduced weight by ten percent and lowered production costs by twenty-five percent compared to existing connecting rods.

3 RESEARCH GAP

In the past, the materials analyzed for connecting rods included Aluminum Alloys and Composites, whereas the current focus has shifted towards Steel. However, there are still numerous unexplored material combinations, and their potential impact on the industry remains uncertain. After a comprehensive review of various journals, we have chosen to advance our project by considering Carbon fibre , Aluminum Alloy, Titanium Alloy, and Aluminum-Silicon Carbide Composite , copper alloy, zinc pure , grey cast iron and structural steel . We plan to conduct Force Analysis using ANSYS workbench software based on these materials .

4 OBJECTIVES

The objective or ambition of the present work is to design and statical structural analysis of Connecting rod to achieve following three main objective of this research paper :

- 1.Enhancing Engine Efficiency through Connecting Rod Weight Reduction.
- 2.Enhancing Connecting Rod Strength and Stiffness.
- 3.Improving Connecting Rod Durability.

5 RESEARCH METHODOLOGY

This section provides a concise overview of the methodology employed to carry out this project. The subsequent flowchart illustrates the step-by-step process of our methodology.

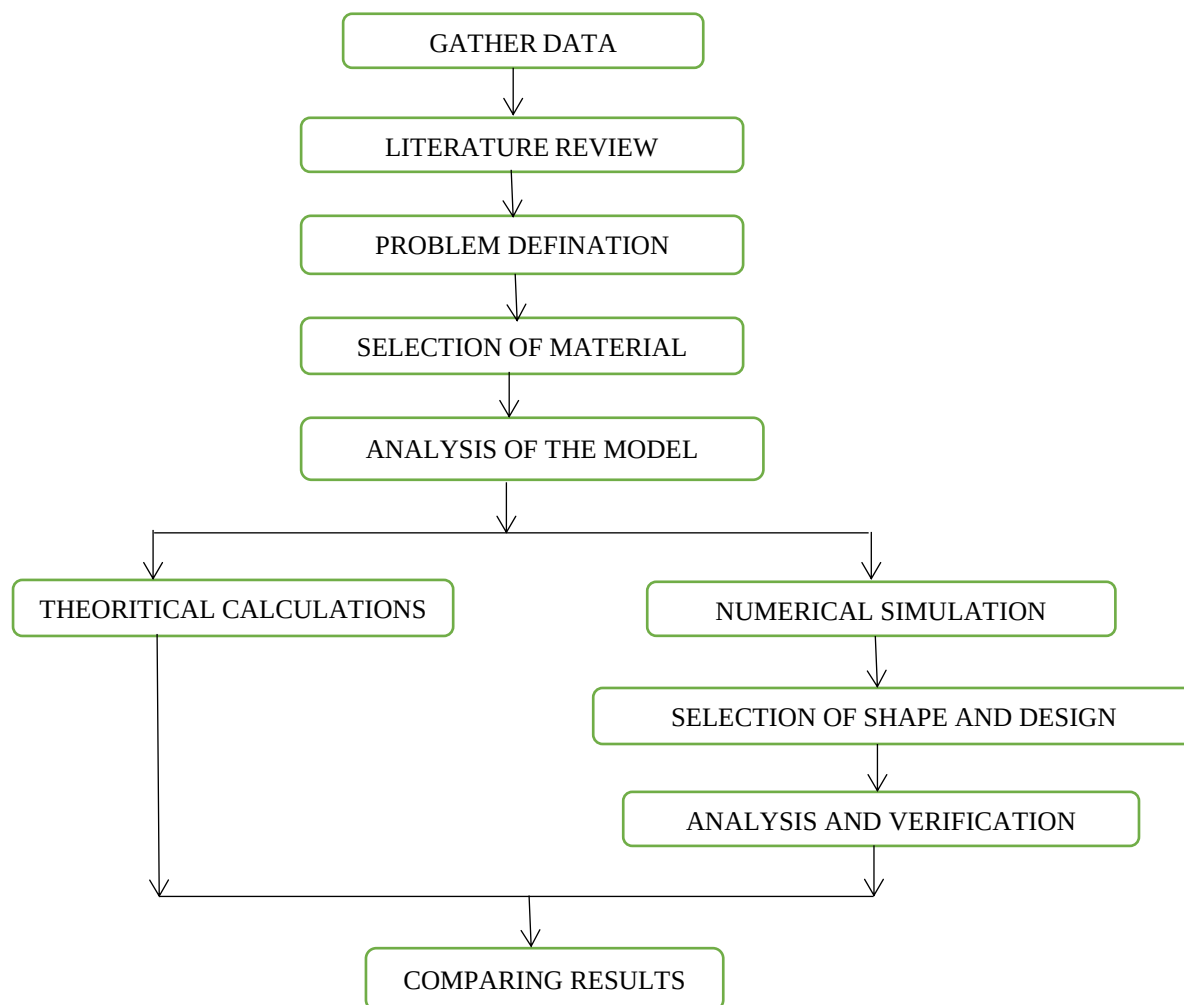


Fig. 2 Research methodology flowchart

6 DESIGN AND DIMENSION OF CONNECTING ROD

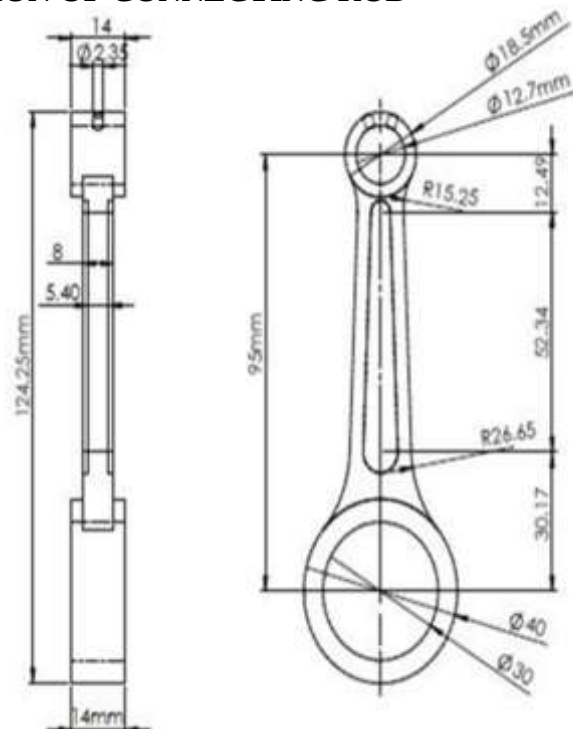


Fig. 3 Design and dimension of connecting rod

7 MATERIALS

- The materials were chosen based on their strength-to-weight ratio, with the aim of increasing strength while concurrently reducing weight. The selected materials include Carbon Fiber, Titanium Alloy, Aluminum Alloy, Copper Alloy, Gray Cast Iron, and Pure Zinc. The results from the analysis of these materials will be compared with the conventional connecting rod material, which is carbon steel. Here is a table summarizing the properties of these materials:

Table1. Materials with properties along with strength to weight ratio

Material	Strength-to-Weight Ratio	Other Properties
Carbon Fiber	High	Lightweight, excellent tensile strength
Titanium Alloy	High	Lightweight, excellent corrosion resistance
Aluminum Alloy	High	Lightweight, good strength
Copper Alloy	Moderate	Good electrical conductivity, corrosion resistance
Gray Cast Iron	Moderate	Good wear resistance, castability
Pure Zinc	Low	Lightweight, corrosion resistance
Structural Steel (Standard)	Moderate	High strength, moderate weight

- Given below are some approximate values of different mechanical properties of materials . Need to Keep in mind that these values can vary depending on specific alloys, grades, and manufacturing processes, so it's always best to refer to material data sheets for precise information. Here are some approximate values:



Table2. Different mechanical properties of material with approximate value

Material	Density (g/cc)	Young's Modulus (GPa)	Poisson's Ratio	Yield Strength (MPa)	Tensile Strength (MPa)	Endurance Limit (MPa)
Zinc (Pure)	7.14	96	0.25	40	150	15-40 Varies with the specific composite
Structural Steel	7.85	200	0.29	250	400-550	120-180 Varies with the specific composite
Carbon Fiber	Varies with the specific composite 1.5 (approx.)	200-800	Varies with the specific composite 0.2-0.3 (approx.)	Varies with the specific composite 600-900 (approx.)	Varies with the specific composite 1000-2000 (approx.)	300-800 Varies with the specific composite
Aluminum Alloy	2.70	69	0.33	276	310	40-140 Varies with the specific composite
Titanium Alloy	4.43	113	0.32	880	950	350-500 Varies with the specific composite
Copper Alloy	8.92	117	0.34	210	220	30-60 Varies with the specific composite
Grey Cast Iron	Varies with the specific composite	100-170	Varies with the specific composite	90-250	180-500	30-70 Varies with the specific composite

- Endurance limit varies significantly based on factors like load conditions, surface finish, and other environmental factors, and it's typically not specified for all materials. For specific values, you would need to consult material data sheets or references for the exact alloys and grades you're interested in.

8 MODELLING AND ANALYSIS

8.1 MODELLING

- The initial step in the analysis process involves modeling a mechanical component, which serves as the foundation for virtual simulations to assess the performance of each section of the connecting rod under specific conditions. To create a standard model of the Connecting Rod, we employed CATIA modeling software.
- CATIA, short for Computer Aided Three-Dimensional Interactive Application, is a sophisticated and globally recognized product design software. It is developed by Dassault Systèmes, a multinational software company headquartered in France. CATIA's versatility extends to creating 3D designs, evaluating computer-aided engineering solutions, implementing product lifecycle management (PLM), and establishing computer-aided manufacturing solutions.
- This software finds extensive use in manufacturing industries and by Original Equipment Manufacturers (OEMs) for enhancing the design, analysis, and management of new products. It transcends traditional Computer Aided Design (CAD) software and offers a complete software suite that encompasses CAD, Computer-Aided Engineering (CAE), and Computer-

Aided Manufacturing (CAM). Due to its intricacy and adaptability, CATIA is considered the industry standard software for executing highly complex simulations.

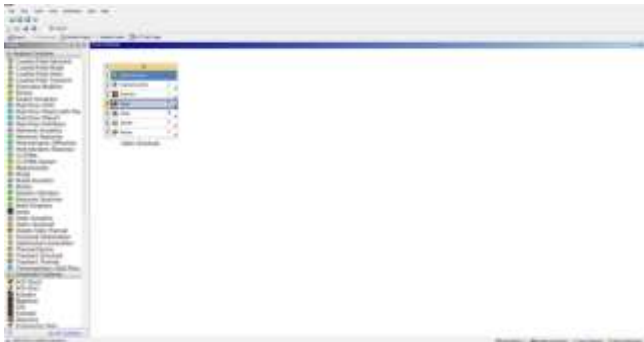


Fig. 4 Ansys student interface

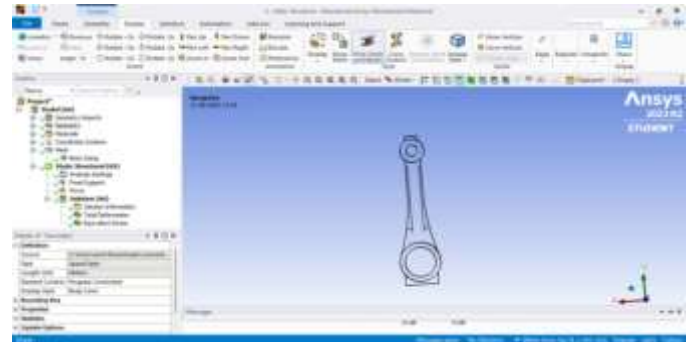


Fig. 5 Geometry of connecting rod in ansys workbench

- Before embarking on the modeling of the connecting rod, it is imperative to ascertain its standard dimensions. To achieve this, a set of design calculations must be carried out, taking into account all pertinent assumptions. These calculations will help determine the theoretical loads exerted on the connecting rod. Once all the essential data is gathered, a standardized connecting rod model can be constructed using CATIA modeling software.
- The acquired model is subsequently employed to conduct simulations, enabling the observation of how the connecting rod responds when subjected to different loads under specific conditions. Various composites are sequentially implemented, and simulations are performed on each of them to assess their performance.



Fig. 6 Three-D model of connecting rod

- Following the completion of the Connecting Rod modeling, the subsequent phase of analysis involves conducting simulations on the created model while adhering to the predefined assumptions. This is essential to visualize and replicate the behavior of the connecting rod when subjected to predetermined conditions. The objective is to pinpoint structural or material modifications necessary to further enhance the connecting rod's performance.
- For these simulations, we employed the ANSYS - WORKBENCH STUDENT VERSION. ANSYS Inc. is a renowned developer and distributor of multiphysics engineering software. The ANSYS Student Version is a comprehensive bundle built on ANSYS Workbench and includes ANSYS Mechanical, ANSYS CFD, ANSYS Autodyn, ANSYS SpaceClaim, and ANSYS DesignXplorer. This version is widely utilized by students globally and encompasses some of the most advanced and commonly used products in commercial applications.
- Finite Element Analysis (FEM) software i.e ANSYS workbench serves to simulate computer models of structures, electronics, or components of machine. It enables the analysis of attributes such as strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and more. This software equips users with the essential tools to achieve technical depth within the realm of simulation. ANSYS is a formidable and highly regarded software within the engineering industry, known for its power and versatility.



Fig. Stages of Failure of Connecting rod

8.2 STATIC STRUCTURAL ANALYSIS

- In this research project, we conducted a static structural analysis, which serves to determine the displacements, stresses, strains, and forces within structures or components under loads that don't induce significant inertia and damping effects. ANSYS software was used to perform this static structural analysis. The types of loading applicable in a static analysis encompass externally applied forces and pressures, as well as steady-state inertial forces.
- For our analysis, we assumed steady loading and response conditions. This means that the loads and the structure's response to these loads change slowly with respect to time. The static structural analysis in this project involved the following steps:
 - The meshed connecting rod was fixed at the crank end, and a force was applied at the piston end.
 - We then selected the necessary results, and the problem was solved.
 - The obtained results were recorded and tabulated for further analysis.

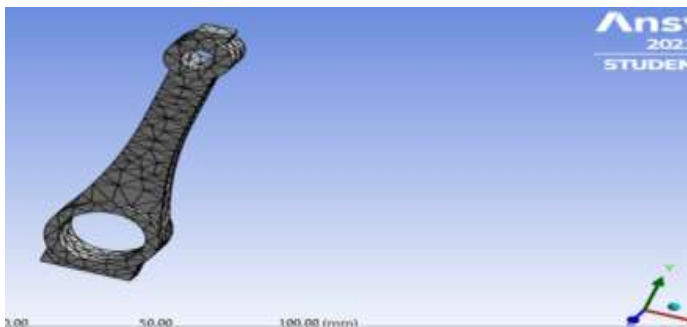


Fig. 7 General Meshing with Default Element size – 8.3136 mm



Fig. 8 Meshing with refinement of Element size – 3.0 mm

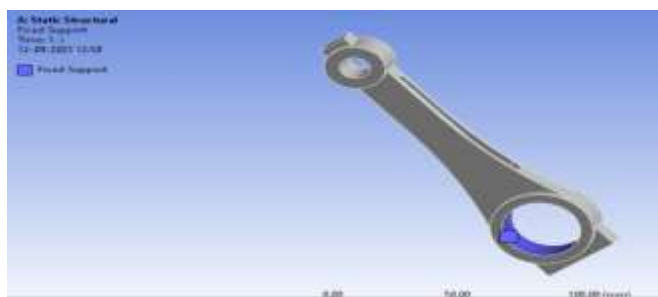


Fig. 9 Fixed Support at big end bore

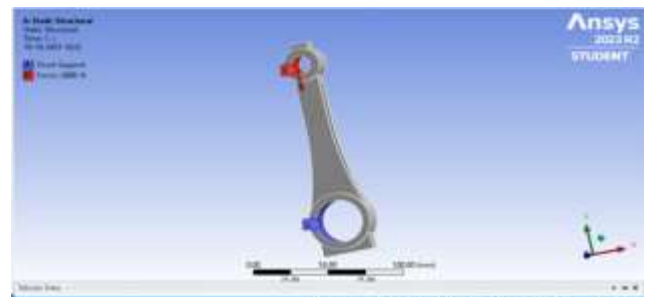
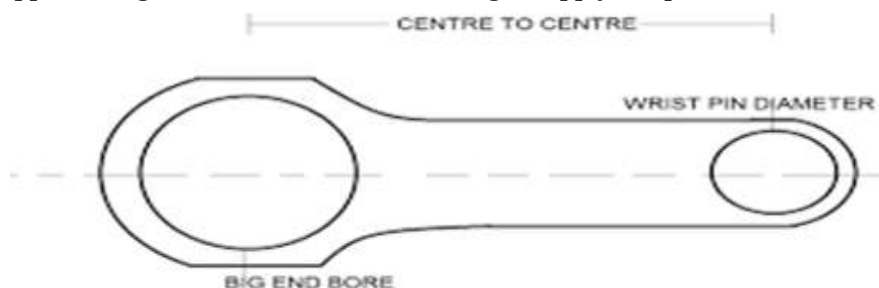


Fig.10 Apply compressive force 2000 N towards fixed support



9 RESULT AND DISCUSSION

FOR STRUCTURAL STEEL

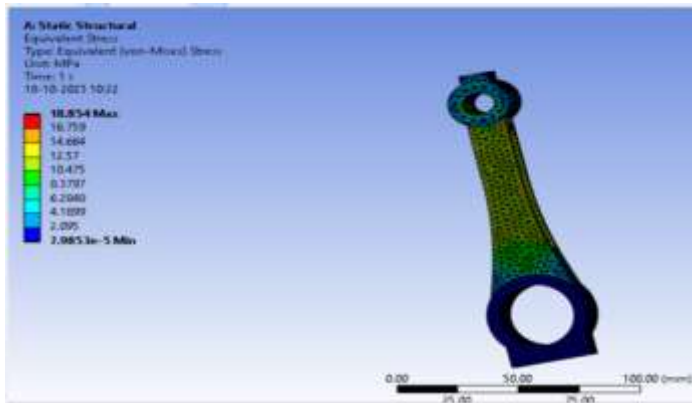


Fig. 11 Equivalent (Von-Mises) Stress Distribution for Steel

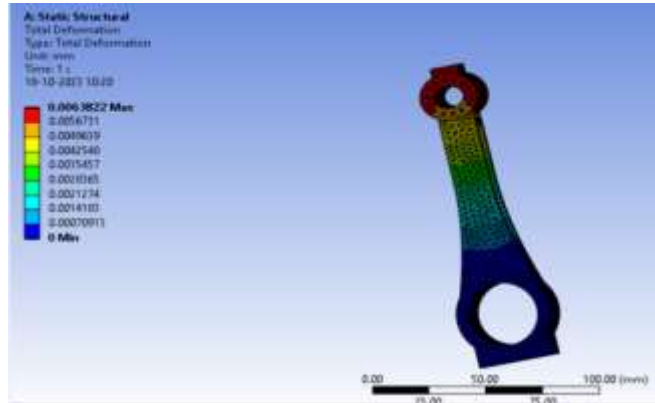


Fig. 12 Total deformation for steel

- The maximum stress and the total deformation for structural steel is 18.854MPa and 0.0063822mm respectively .



Fig. Industry Used Connecting Rod Made up of Steel

FOR ALUMINIUM ALLOY

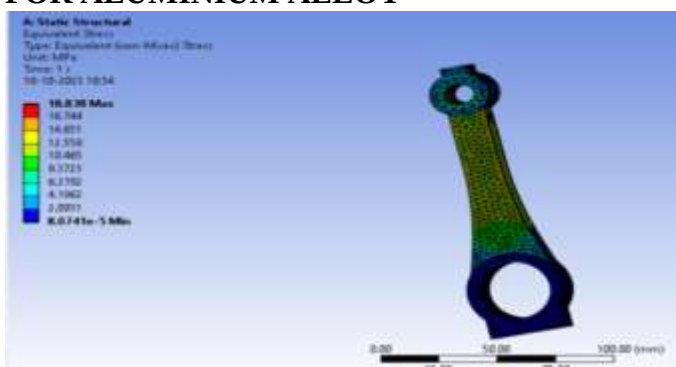


Fig. 13 Equivalent Stress distribution for aluminium alloy

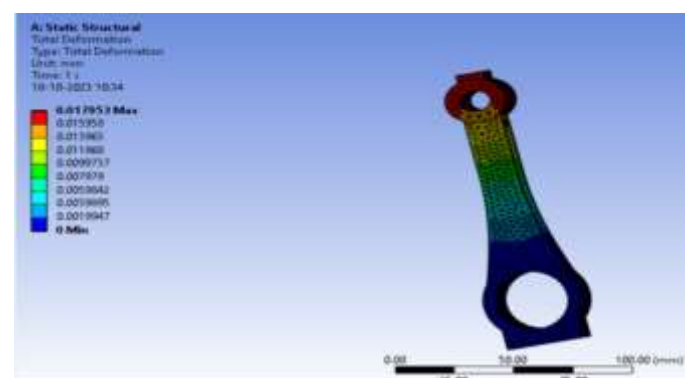
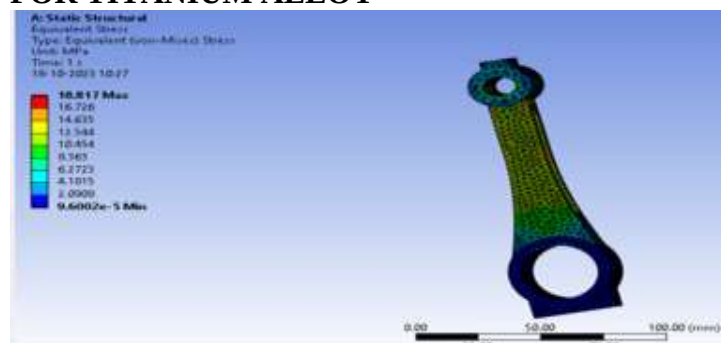
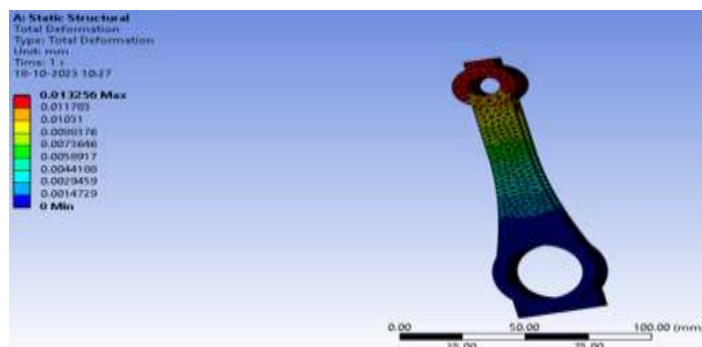
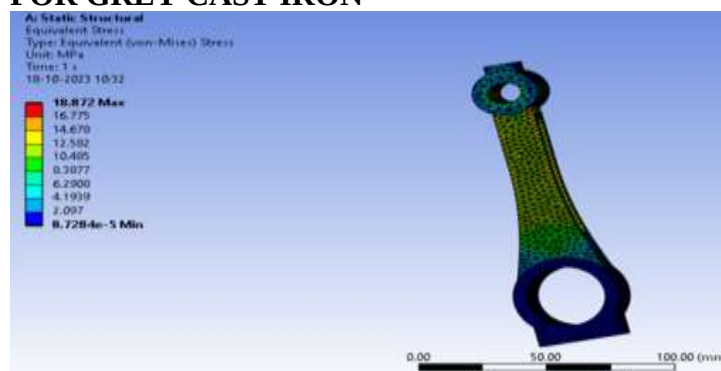


Fig. 14 Total deformation for aluminium alloy

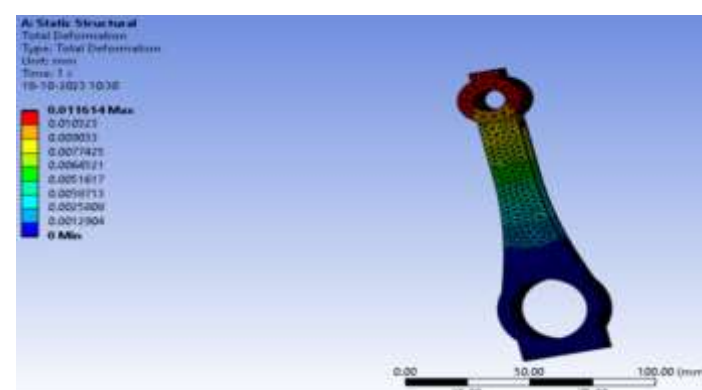
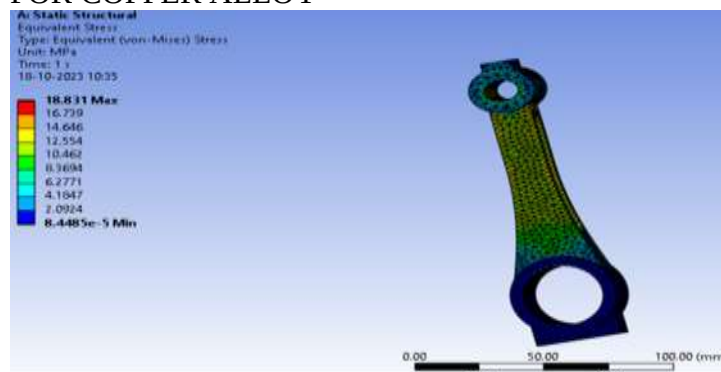
- The maximum stress and the total deformation for aluminium alloy is 18.838MPa and 0.017953mm respectively .

FOR TITANIUM ALLOY**Fig. 15 Equivalent stress distribution for titanium alloy**

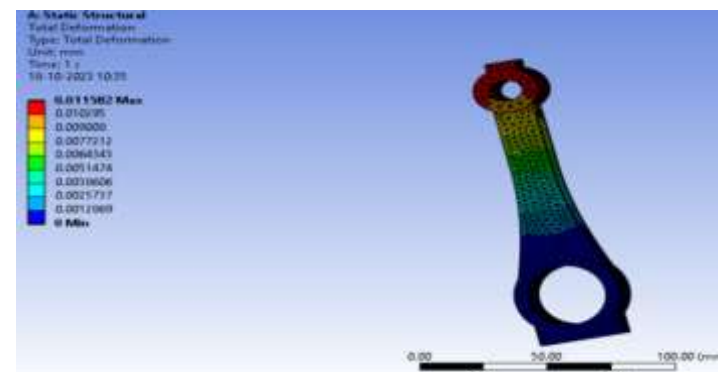
- The maximum stress and the total deformation for titanium alloy is 18.817MPa and 0.013256mm respectively

**Fig. 16 Total deformation for titanium alloy****FOR GREY CAST IRON****Fig. 17 Equivalent stress distribution for grey cast iron**

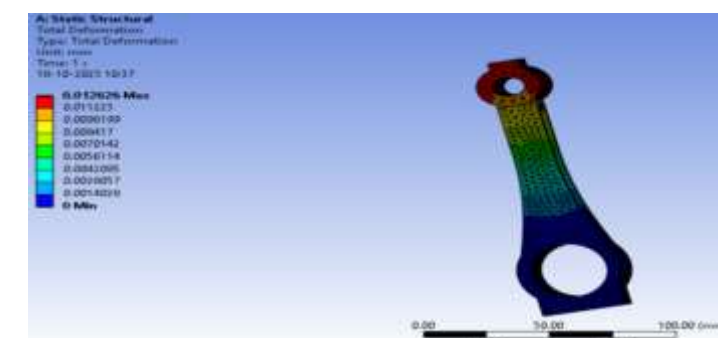
- The maximum stress and the total deformation for grey cast iron is 18.872MPa and 0.011614mm respectively

**Fig. 18 Total deformation for grey cast iron****FOR COPPER ALLOY****Fig. 19 Equivalent stress distribution for copper alloy**

- The maximum stress and the total deformation for grey cast iron is 18.831MPa and 0.011582mm respectively

**Fig. 20 Total deformation for copper alloy****FOR ZINC PURE****Fig. 21 Equivalent stress distribution for zinc pure**

- The maximum stress and the total deformation for grey cast iron is 18.897MPa and 0.012626mm respectively

**Fig. 22 Total deformation for zinc pure**

FOR CARBON FIBER

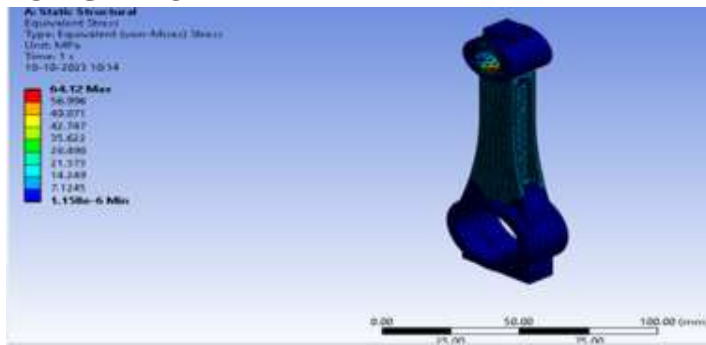


Fig. 23 Equivalent stress distribution for carbon fiber

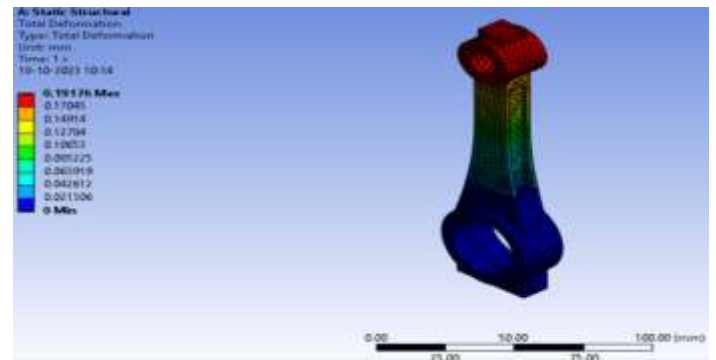


Fig. 24 Total deformation for carbon fiber

- The maximum stress and the total deformation for Carbon fiber is 64.17MPa and 0.19176mm respectively.
- ❖ The results provided above were derived from the static structural analysis. The outcomes of the structural analysis are detailed in the results table below.

Table 3 Results table

Parameters/ Materials	Von Mises Stress	Strain	Total Deformation
Structural steel	18.854	$9.447e^{-5}$	0.0063822
Aluminium alloy	18.838	0.00026589	0.017953
Titanium alloy	18.817	0.00019644	0.013256
Grey Cast Iron	18.872	0.00017188	0.011614
Copper alloy	18.831	0.00017156	0.011582
Zinc Pure	18.897	0.00018688	0.012626
Carbon Fiber	64.12	0.0033028	0.19176

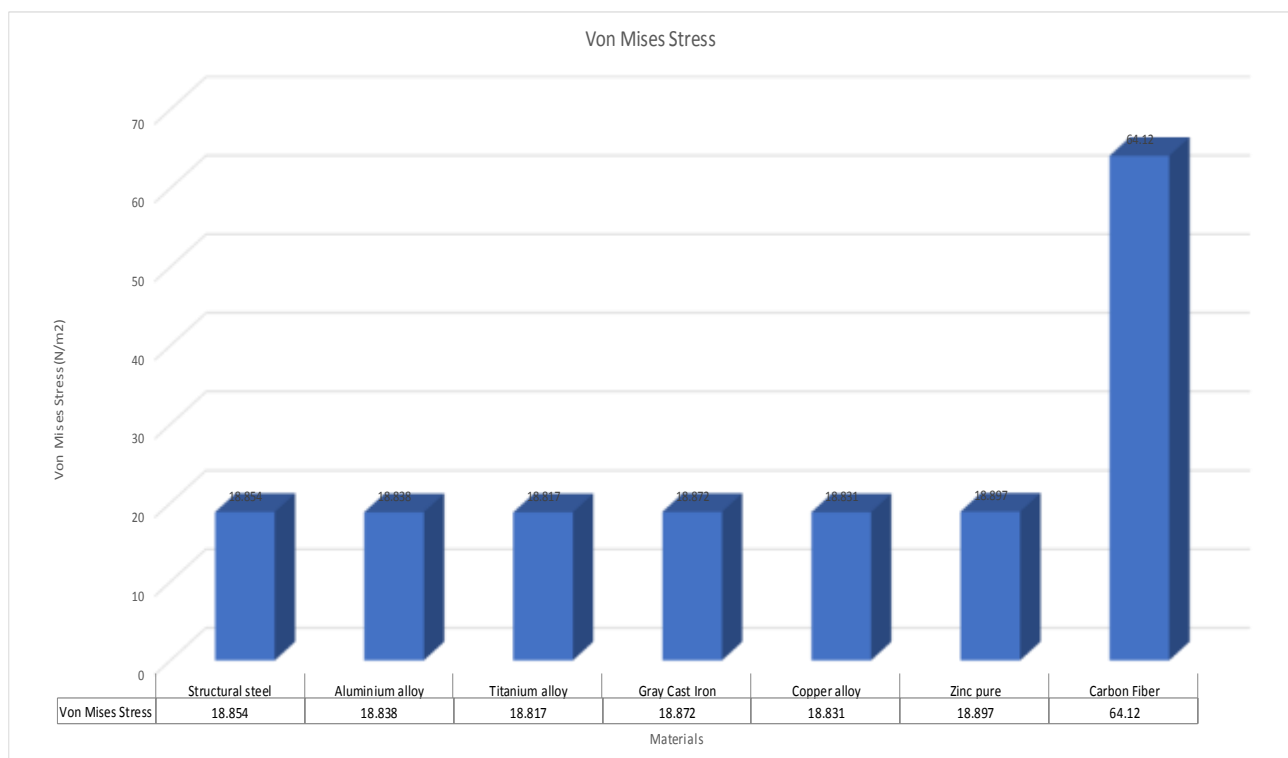


Chart – 1: Comparison of von mises stress of all material

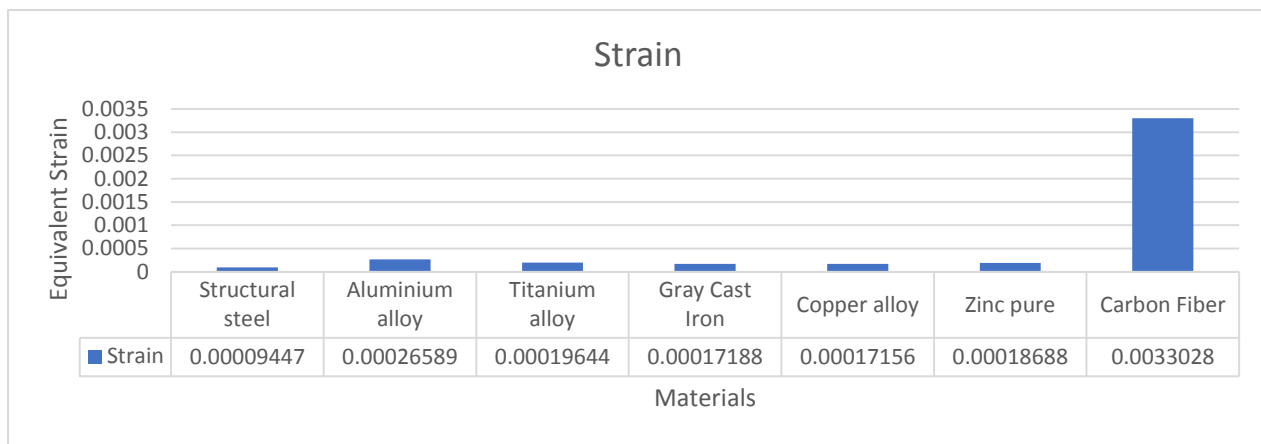


Chart – 2: Comparison of Equivalent strain of all material

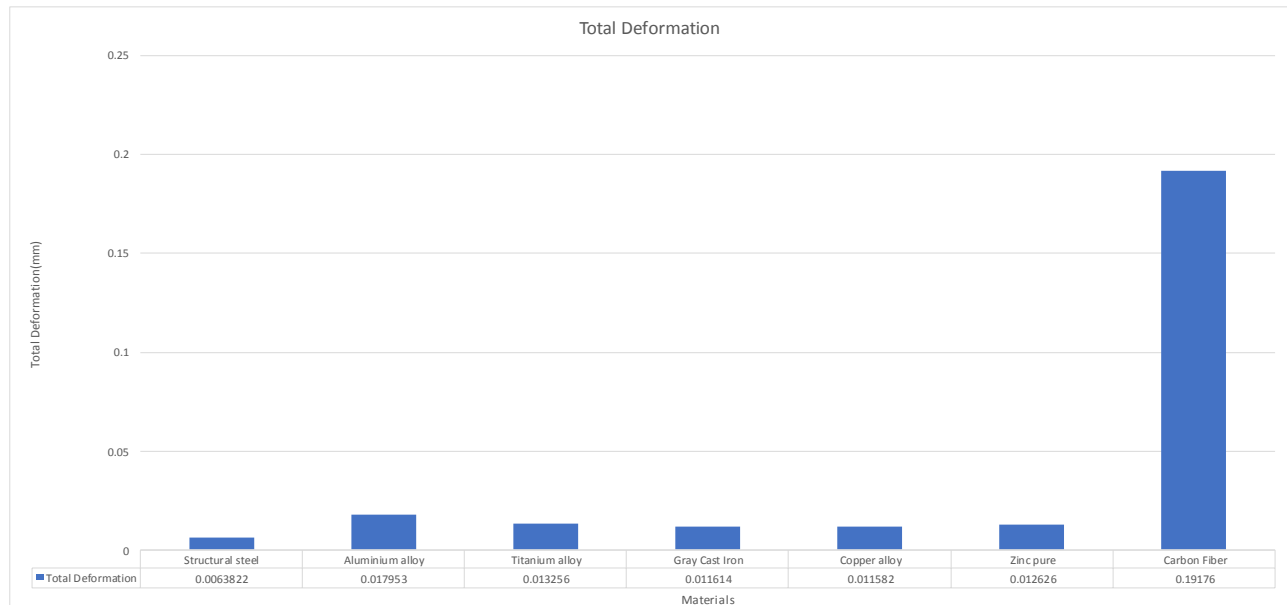


Chart – 3: Comparison of total deformation of all materials

10 CONCLUSIONS

In this study, we performed finite element analysis of a connecting rod using the ANSYS simulation tool. Our objective was to assess the impact of material selection on connecting rod design by considering various materials. We conducted a series of simulations, which revealed a significant range of variations in factors such as Equivalent von-Mises stresses, Equivalent elastic strain, Total deformation, and Factor of safety for the different materials under consideration. To enhance the connecting rod's design, we made minor adjustments without altering its primary dimensions.

- I. We initiated the project by creating a solid model of the connecting rod in CATIA , following the design specifications. Subsequently, we conducted an analysis under both tensile and compressive loads using ANSYS Workbench.
- II. Our analysis revealed that the connecting rod experiences minimum stresses at the crank end and maximum stresses at the piston end. Therefore, there is potential to reduce material at the crank end, thus lowering material costs. Conducting dynamic analysis can further optimize the connecting rod's design.
- III. Based on our study, we can conclude that the connecting rod can be designed and optimized to withstand both compressive and tensile loads, utilizing lighter materials that offer improved performance and efficiency compared to steel.
- IV. The analysis conducted in this work indicates that the stresses in all the materials are comparable and well within the safe limit, remaining significantly below the yield stress.
- V. The lighter materials utilized in the analysis exhibit superior section modulus compared to the existing steel connecting rod, which helps prevent high bending stresses caused by inertia forces.
- VI. Reducing the weight of the connecting rod effectively mitigates inertia forces. The results of the materials analyzed were compared with the current material, carbon steel, revealing that the equivalent stresses for all materials were quite similar.

- VII. Our static analysis demonstrated that the equivalent stress reaches its maximum value at the I-section near the larger end of the connecting rod.
- VIII. It was observed that the connecting rod made of carbon steel has a lower strength-to-weight ratio compared to the other materials under consideration.
- IX. Maximum stress is observed in carbon fiber among all materials that is 64.12 , while lowest strain and total deformation observed in structural steel that is 9.447×10^{-5} and 0.0063822 respectively .

11 FUTURE SCOPE

1. Conducting a dynamic analysis of the connecting rod can provide a more comprehensive assessment of its performance.
2. A thermal analysis of the connecting rod can effectively mitigate the impact of thermal stresses on its integrity.
3. Considering the presence of a minor torsional moment at the end points, performing torsional analysis can offer valuable insights.
4. To determine the service life of the connecting rod, fatigue analysis can be conducted, taking into account cyclic loading.
5. To reduce wear-related failures, it's beneficial to explore internal coatings as a means of wear reduction.
6. Implementing modal analysis can help in the prevention of premature failures by identifying critical resonant frequencies and mode shapes.

REFERENCES

- [1] A. Pandiyan, G. Arunkumar and G. Premkumar. 2019. "Design, Analysis and Topology Optimization of a Connecting Rod for Single Cylinder 4-Stroke Petrol Engine", January 2020, International Journal of Vehicle Structures and Systems 11(4):439-442.
- [2] Shubham Tiwari, Ajay Kumar Kaviti – "Parameters influencing connecting rod: A Review", International Journal of Scientific & Engineering Research, Volume 6, Issue 8, August-2015 8 ISSN 2229-5518 IJSE © 2015.
- [3] Vikas Singh, Sumit Kr. Verma, Harish Chandra Ray, Vishal Kr. Bharti, Abhinesh Bhaskar - "Design and Analysis of Connecting Rod for Different Material Using ANSYS Workbench 16.2." International Journal of Engineering and Advanced Technology (IJEAT), ISSN: 2249 – 8958, Volume-9 Issue-3, February 2020.
- [4] Somnath Chattopadhyay - "SELECTION OF MATERIAL, SHAPE, AND MANUFACTURING PROCESS FOR A CONNECTING ROD", AC 2010-926.
- [5] Adnan Ali Haider, Akash Kumar, Ajinkya Chowdhury, Moin Khan, P. Suresh - "Design and Structural Analysis of Connecting Rod", International Research Journal of Engineering and Technology (IRJET), Vol. 5 Issue 5, May 2018, Pg. 282-285.
- [6] Kuldeep B, Arun L.R, Mohammed Faheem "ANALYSIS AND OPTIMIZATION OF CONNECTING ROD USING ALFASiC COMPOSITES", ISSN: 2319- 875, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 6, June 2013.
- [7] Ashby, M. F., Shercliff, H., and Cebon, D. (2008) – "Materials: Engineering, Science, Processing and Design", Butterworth - Heinmann, Paperback ISBN: 9780081023761.
- [8] Mr. H D. Nitturkar, Mr. S M. Kalshetti, Mr. A R. Nadaf – "Design and Analysis of Connecting Rod using Different Materials", Volume: 07 Issue: 03, Mar 2020.
- [9] Pravardhan S. Shenoy and Ali Fatemi - "Connecting Rod Optimization for Weight and Cost Reduction" 2005, SAE International, International Journal of Latest Trends in Engineering and Technology (IJLTET) Vol. 1 Issue 3 September 2012, ISSN: 2278-621X.
- [10] Mirehei, A., Zadeh, M.H., Jafari, A. and Omid, M. (2008) - "Fatigue analysis of Connecting Rod of universal tractor through finite element method (ANSYS)", Journal of Agricultural Technology 4(1): 21-27.
- [11] "Design Data Handbook for Mechanical Engineers – Fourth Edition" by K. Mahadevan and K. Balaveera Reddy published by CBS Publishers & Distributors Pvt. Ltd.