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Design And Comparative Analysis Of Ic Engine Connecting Rod Using Different Materials With Ansys Software 25r1

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Abstract:

The connecting rod is an intermediate component that links the piston to the crankshaft. Its primary function is to transfer the push and pull forces from the piston pin to the crank pin, thereby converting the reciprocating motion of the piston into the rotary motion of the crankshaft. This thesis focuses on the design and comparative analysis of an internal combustion (IC) engine connecting rod of a four-stroke single-cylinder connecting rod for the Bajaj Pulsar NS-400Z engine based on various materials such as Forged steel (AISI 4140), Aluminum Alloy (A4032), And Gray cast iron. Currently, the existing connecting rods are manufactured using materials such as Stainless steel and carbon steel. In this study, the design drawings are drafted based on detailed calculations. A parametric model of the connecting rod is created using CATIA V5 software, and structural analysis is performed using ANSYS 2025 R1 Workbench software. The analysis evaluates key parameters like von Mises stress, strain, and deformation for a two-wheeler IC engine piston using ANSYS 2025 R1 software. The results indicate that forged steel (AISI 4140) exhibits greater strength and less deformation compared to other materials like Aluminum Alloy (AISI 4032) and grey cast iron.

Keywords: Connecting Rod, Aluminium Alloy (AISI 4032), Forged Steel (AISI 4140), Ansys Workbench, CATIA V5, Gray cast iron etc.

INTRODUCTION:

The connecting rod is one of the most critical components in an internal combustion (IC) engine, playing a crucial role in converting the reciprocating motion of the piston into the rotary motion of the crankshaft. It is subjected to complex loading conditions, including compressive and tensile forces due to combustion pressure and inertial forces caused by the reciprocating masses. as a result, the design and material selection of the connecting rod significantly influence the performance, durability, and efficiency of the engine. With the increasing demand for high performance, lightweight, and fuel-efficient engines, optimizing the connecting rod's design and material has become a key focus in the automotive industry, In this study the design and comparative analysis of an I-section connecting rod are conducted using three different materials such as Forged Steel (AISI 4140), Aluminum Alloy (AISI 4032), and Gray Cast Iron. The I section is chosen for its optimal strength-to-weight ratio, making it a widely used design in connecting rods. The design of the connecting rod is Model using CATIA V5, a leading computer-aided design (CAD) software, ensuring precision and accuracy in the geometric representation. The structural analysis is performed using ANSYS 2025 R1, a powerful finite element analysis (FEA) software, to evaluate the performance of the connecting rod under various loading conditions [1],[2]. The most common types of materials used for connecting rods are steel and aluminium. Connecting rods are widely used in variety of engines such as, in-line engines, V-Engines, opposed cylinder engines, radial engines and oppose-piston engines. For the project work we have selected connecting rod used in light commercial vehicle of tata motors had recently been launched in the market. We found out the stresses developed in connecting rod under static loading with different loading conditions of compression and tension at crank end and pin end of connecting rod. Generally connecting rods are manufactured using carbon steel and in recent days Aluminium alloys are finding its application in connecting rod. In this work connecting rod is replaced by Aluminium based composite material reinforced with silicon carbide and fly ash. And it also describes the modelling and analysis of connecting rod. FEA analysis was carried out by considering two materials. The parameter like von-misses stress, von- misses strain and displacements were obtained from ANSYS software. [3] focuses on optimum shape, manufacturing process for better material properties and the suitable alloys and composites for connecting rod. Powder Metallurgy was studied and it was found that it strengthens the microstructure and better mechanical property of connecting rod can be obtained. They inferred that if instead of Steel we use Titanium Alloy to manufacture Connecting Rod using this, method then tensile elongation of connecting road and tensile strength can be enhanced to a greater extent. [4]. The stress and strain analysis for different materials and compared them with each other. When boundary conditions are applied on connecting rod, using finite element analysis the unknown variables such as deformation, strain and stress are found. The solution was obtained for Equivalent Elastic Strain and Total deformation using different materials one after the other [5]. The Results has done the required basic calculations for the selection of the material and also provided information about suitable manufacturing process for different materials.[6],[7],[8]. concluded that the Titanium Alloy suites best for manufacturing of Connecting Rod. As because it has the best Factor of Safety with regard to its weight and minimum deformation. This was followed by Aluminium Alloy 7075T6, which had lower Factor of Safety as compared to Titanium Alloy, but the weight was much lower than that of the Titanium Alloy. Al introduced the finite element analysis procedure for improving the connection rod weight and cost reduction. A study was conducted on connecting rod made forged Steel with a thought of improving the weight and production cost. Weight was reduced by an iterative procedure this study resulted in new connecting rod was ten percent lighter and twenty-five percent less expensive when compared to the existing connecting rod. as looked at the reforming the connecting rod made of Steel and have arrived at the list of processes, that is - (1) Die casting (2) forging and machining (3) powder methods and machining. They have discovered that for a production of ten thousand components, forging comes out the cheapest then followed by Di casting. Powder methods are comparatively costlier because slow production cost and capital cost.

"Based on the shape of the cross section of the connecting rod they are classified mainly into four categories:

1. I - section Connecting Rod
2. H - section Connecting Rod
3. Rectangular section
4. Circular section "

Among the various cross-Sections analysis, circular and rectangular cross-sections are found to be the most stressed cross sections. leading to their exclusion from further consideration. The remaining two cross-sections demonstrated lower stress concentrations and delivered better performance. But I-section stood out due to its superior shape factor in bending, offering advantages in both strength and stiffness effect. As a result, the I-section was chosen as the preferred design for the connecting rod, particularly when using Carbon steel. In this study the conventional connecting rod material was replaced with Forged steel (AISI 4140), Aluminum alloy (AISI 4032), And Gray cast iron. Finite element analysis (FEA) was conducted to evaluate the performance of the materials, with key parameters such as Equivalent (von-mises) stress, strain, and Total deformation.

OBJECTIVES:

1. Increasing the efficiency of the engine by reducing the weight of the connecting rod.
2. Increasing the strength and stiffness of the connecting rod.
3. Increasing the durability of connecting rod.
4. To analysis the buckling load which is equivalent stress due to inertia forces acting on each material of connecting rod.

MATERIALS AND METHODOLOGY:

Engine Specifications:

In this work for designing the I-section connecting rod, the following specifications are taken into consideration of an IC-Engine of model **Bajaj Pulsar NS-400Z** S.I, 4 Stroke air cooled petrol engine.

Table -1 Engine specifications

S.NO	PARAMETERS	VALUES
1.	BORE DIAMETER × STROKE LENGTH	89 MM × 64 MM
2.	STROKE VOLUME	373 CC
3.	MAXIMUM POWER	40 PS @ 8800 RPM
4.	MAXIMUM TORQUE	35 PS @ 6500 RPM
5.	COMPRESSION RATIO	11.6:1
6.	FUEL USED	PETROL
7.	MOLECULAR WEIGHT, (me)	114.228 G/MOLE
8.	UNIVERSAL GAS CONSTANT, (R)	8.314 J/MOL-K
9.	CRANK RADIUS	32
10.	DENSITY OF PETROL	737.22 KG/M3
11.	MASS OF PETROL	0.2752 KG
12.	TEMPERATURE OF PETROL	288.855K
13.	F.O.S IS ASSUMED	2

PROPERTIES OF MATERIALS:

MATERIALS:

Forged Steel (AISI 4140):

Forged steel 4140 is a low-alloy steel containing chromium, molybdenum, and carbon. Known for its high strength, toughness, and excellent fatigue resistance, it is commonly used in automotive and aerospace applications. It is forged to improve its mechanical properties, making it ideal for demanding applications like connecting rods.

Aluminium Alloy (A4032):

Aluminium Alloy 4032 is a high-performance, heat-treated alloy primarily used in automotive and aerospace applications. It offers excellent strength, wear resistance, and high-temperature performance, making it ideal for engine components like pistons. It is composed of aluminium with silicon, copper, magnesium, and other elements, which enhance its durability and thermal stability. Known for its low thermal expansion and superior fatigue resistance, Alloy 4032 is widely used in high-stress environments where reliability and performance are crucial.

Gray cast iron:

It is the most common cast iron and the most widely used cast material based on weight. It is used for housings where the stiffness of the component is more important than its tensile strength. Such as internal combustion engine cylinder blocks. Pump housings, valve bodies electrical boxes, and decorative castings. A typically chemical composition to obtain a graphitic microstructure is 2.4 to 4.0% carbon and 1 to 3% silicon by weight.

Table – 2 Material properties.

Material properties	Forged steel (AISI 4140)	Aluminumn alloy (A4032)	Gray cast iron
Density(g/cm^3)	7.85	2.69	7.2
Yield strength (mpa)	415	315	-
Ultimate yield strength (mpa)	655	380	240
Young's modulus (gpa)	201.6	67.97	110
Poisson's Ratio	0.26	0.31	0.28
Compressive ultimate strength (mpa)	63.47	390	820

METHODOLOGY:

This section gives a brief description about the methodology followed to complete this project.

The following flowchart represents the methodology process:

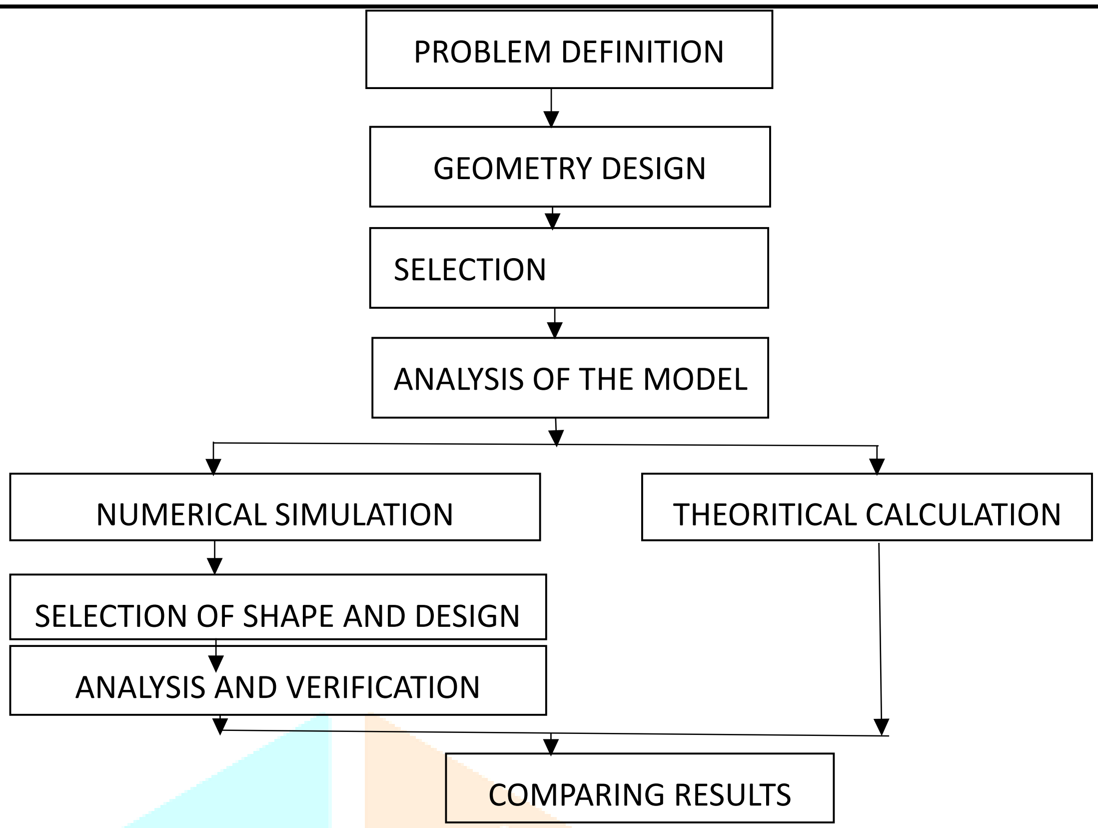


Fig 1: Methodology Flowchart

- I-Section has more shape factor compared to H-section and also bending strength, fatigue are more, hence I-section is being considered for Analysis.
- For **I-Section** Calculation, these are the Standard Parameters:
- Thickness of connecting rod = t
- Width of flange, B = 4t
- Height, H = 5t
- I-Section Area = 11t^2

The maximum force acting on the piston due to gas pressure,

Since the connecting rod is designed by taking the force on connecting rod (Fg) equal to the maximum force on the piston (FL) due to gas pressure, therefore

Fg = π/4×(db)^2×P

Buckling or crippling load on connecting rod,

FB = Fg × F.O.S

Since, Factor of safety considered is 2

From Rankine's formula,

$$F_{cr} = [\sigma_c \times A/1+a(L/K)^2]$$

Where σ_c = 320 mpa (Crushing strength)

K = 4/2500 For steel rod, pin connected at the both end so that the rods is freely bends in any plane.

$$K = ((bh^3-b1h1^3) / 12(bh-b1h1))^{1/2}$$

$$K = 3.175t^2$$

Dimensions of I-Section Connecting Rod

- The dimensions of connecting Rod is tabulated below.

Table -3: Dimensions of Connecting Rod

S. No.	PARAMETERS (mm)
1.	Thickness of Connecting Rod = 4.4
2.	Width of the section (B = 4t) = 17.6 mm
3	Height of the Section (H =5t) = 22 mm
4.	Height at the bigger end = (1.1 to 1.125) H = 24.2 mm
5.	Height at the smaller end = (0.9H to 0.75H) = 19.8 mm
6.	Inner Diameter at Piston End = 34 mm
7.	Outer Diameter at the Piston End = 48 mm
8.	Inner Diameter at Crank End = 68 mm
9.	Outer Diameter at Crank End = 82 mm
10.	Length of the connecting rod = 128

MODELLING AND ANALYSIS:

Modelling a mechanical part is the first basic step of the analysis process, which will later help us to virtually simulate how each and every section of the connecting rod will perform under specified circumstances. In order to create a standard model of Connecting Rod, CATIA V5 modelling software was used. CATIA V5 stands for Computer Aided three Dimensional Interactive Application. CATIA V5 is a highly sophisticated and globally recognised product design software, developed and created by Dassault system. a multinational software company based out of France. CATIA V5 is widely used to create 3D design, to evaluate computer-aided engineering solutions, implement PLM, and establish computer-aided manufacturing solutions.

Buckling Analysis:

Buckling analysis needs to be carried on the connecting rod to know the load at which the buckling failure occurs. Generally there are 2 modes of buckling that occurs in a connecting rod which are:

- Side Buckling (Parallel to the rotational axis)
- Front-Rear Buckling (Perpendicular to the rotational axis).

DESIGN MODEL:

The Cad model of I-section connecting rod is designed in CATIA V5 software and then imported to ANSYS R25 workbench in STP file format.

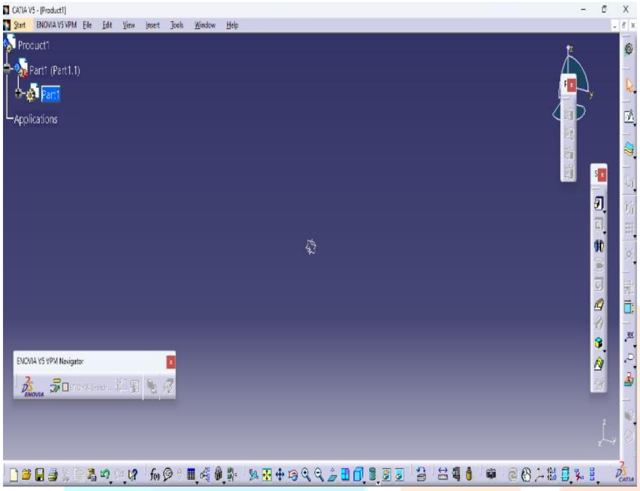
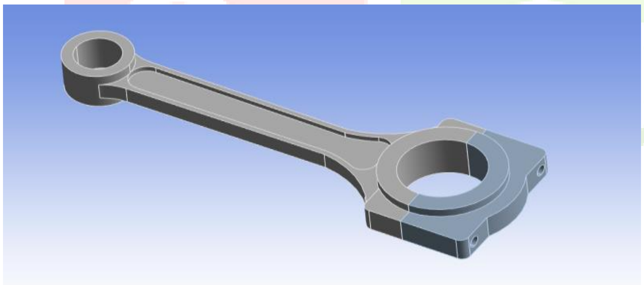


Fig 2: CATIA V5 interface

Fig 3: Connecting rod model in CATIA V5

The isometric view of the connecting rod is in below figure.



RESULTS AND DISCUSSION:

ANSYS Stress Results:

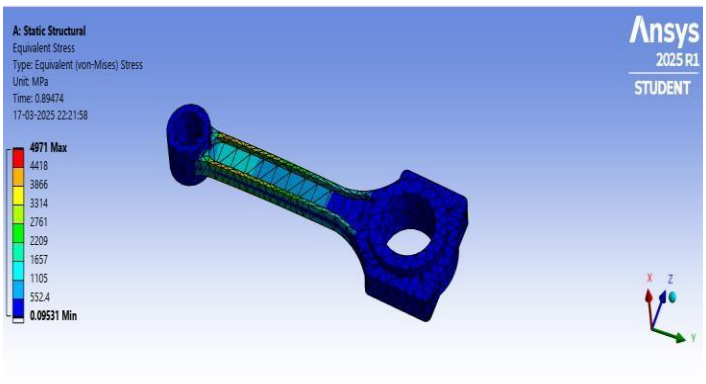


Fig 5: Stress induced in Forged steel (AISI 4140)

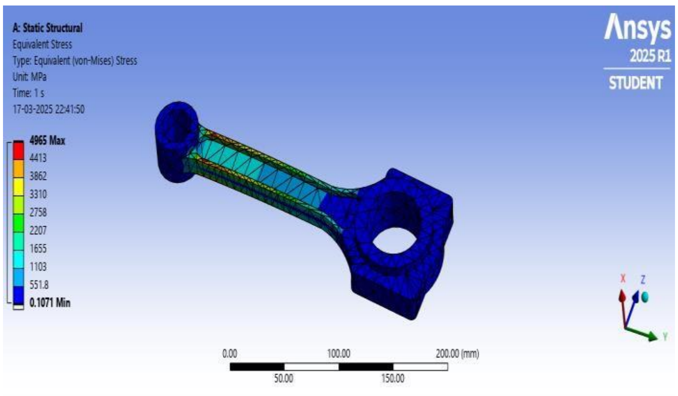


Fig 6: Stress induced in Aluminum Alloy (A4032)

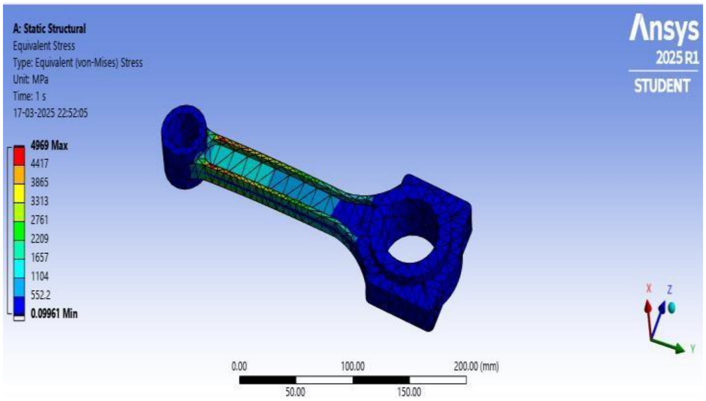


Fig 7: Stress induced in Gray cast iron

ANSYS Strain Results:

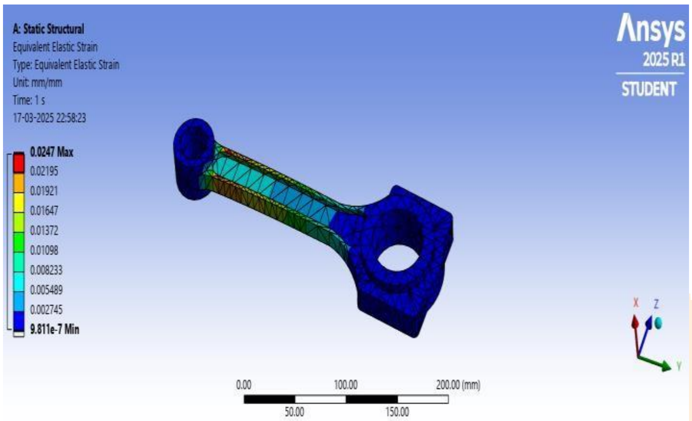


Fig 8: Equivalent Elastic Strain for Forged steel 4140

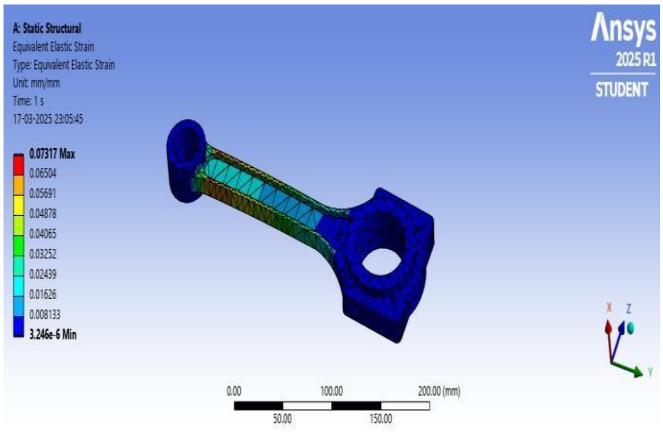


Fig 9: Equivalent Elastic Strain for Aluminum Alloy (A4032)

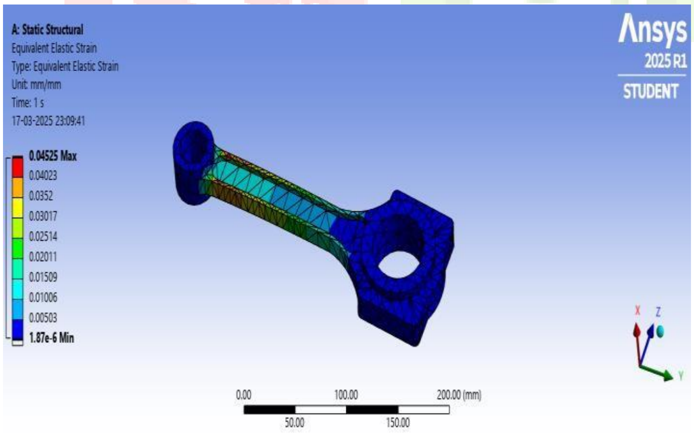


Fig 10: Equivalent Elastic Strain for Gray cast iron

ANSYS Total Deformation Results

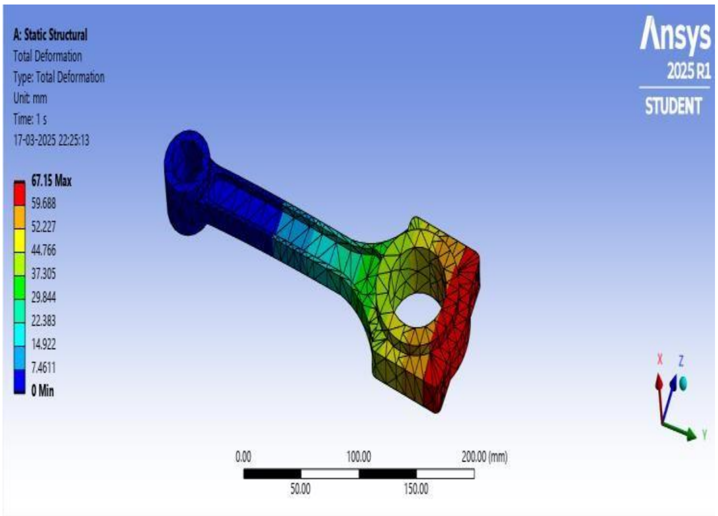


Fig 11: Total Deformation in Forged steel (AISI 4140)

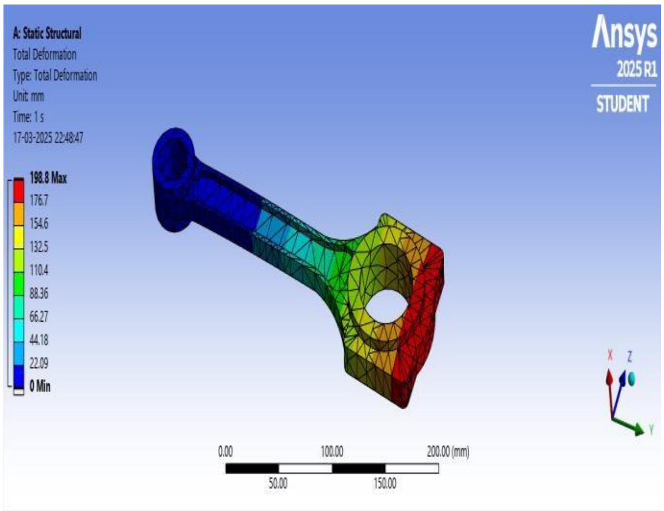


Fig 12: Total Deformation in Aluminum Alloy (A4032)

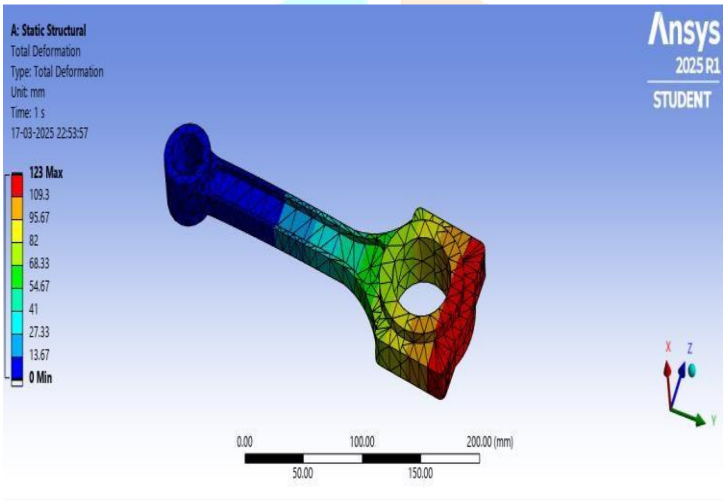


Fig 13: Total Deformation in Gray cast iron

ANSYS Eigen Buckling Results:

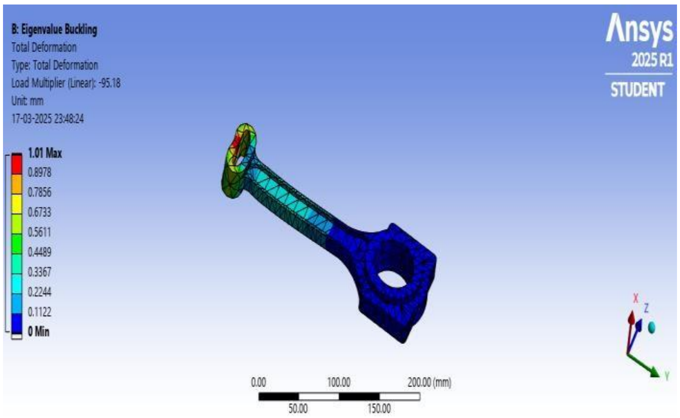


Fig 14: Total Buckling Deformation in Forged steel (AISI 4140)

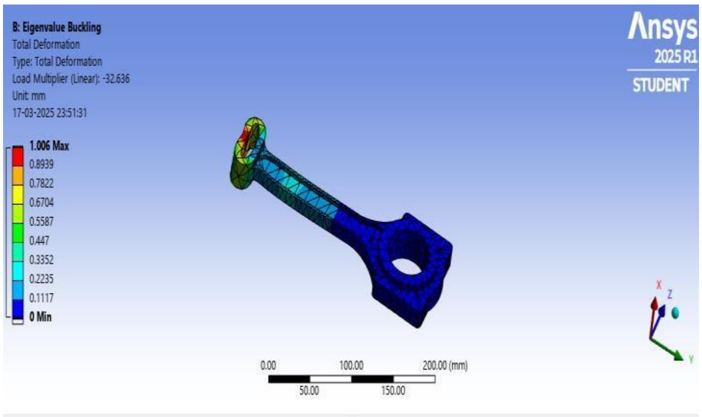


Fig 15: Total Buckling Deformation in Aluminum Alloy (A4032)

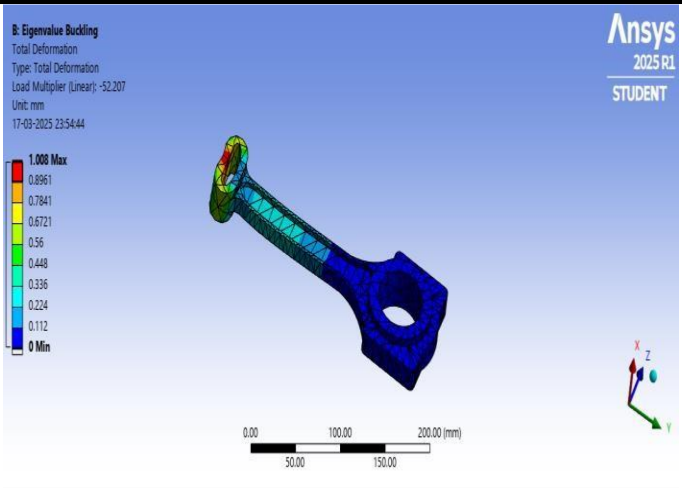
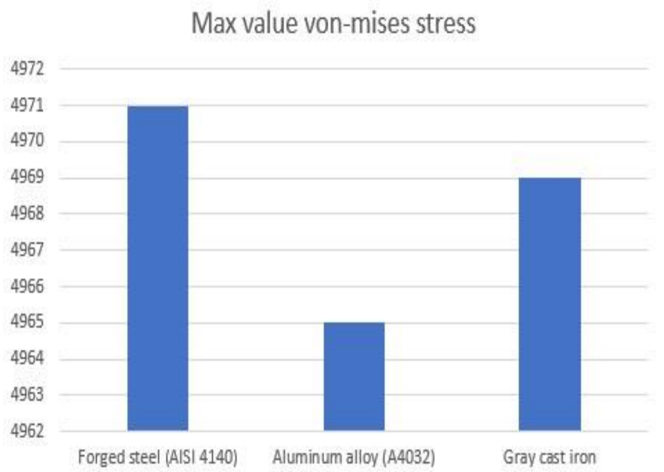


Fig 16: Total Buckling Deformation in Gray cast iron



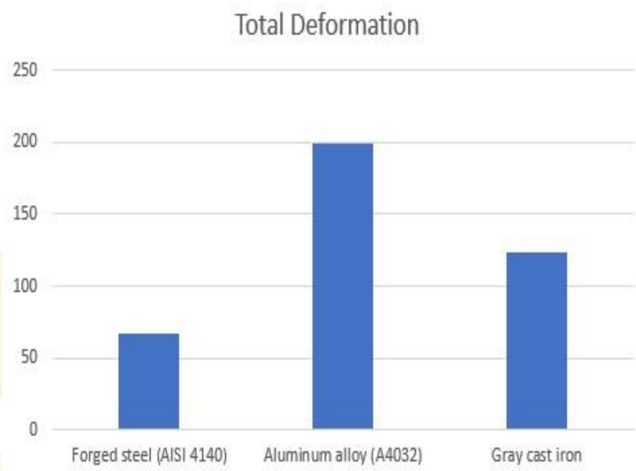
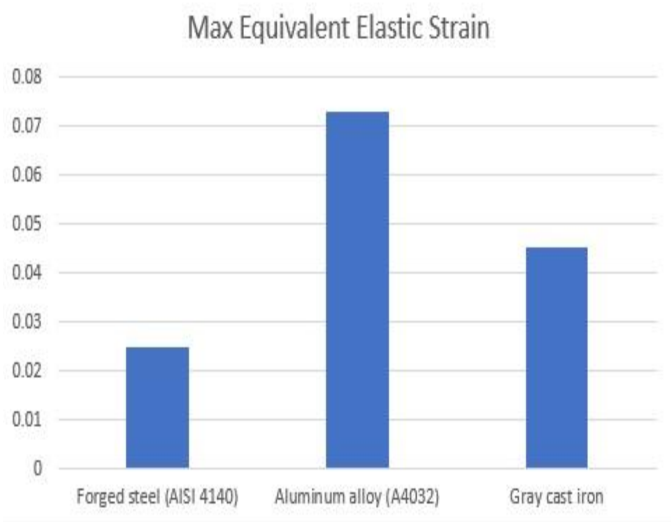


Chart -1: Comparison of Von-Mises Stress of all Materials

Chart -2: Total Deformation



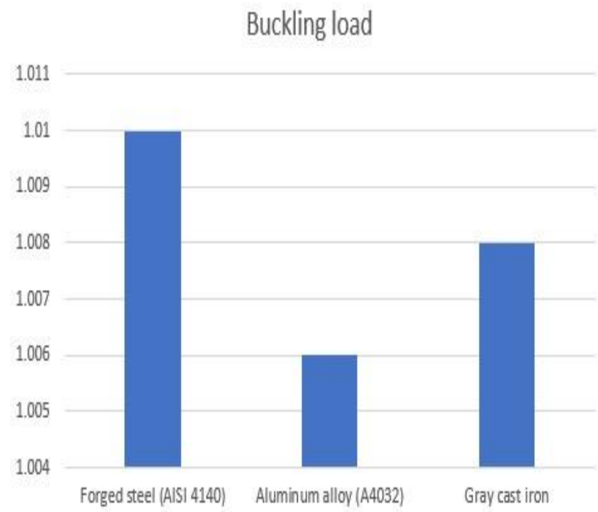


Chart -3: Comparison of Max Equivalent Elastic Strain Of all Materials

Chart -4: Comparison of Buckling load of all Materials

Table -4: Results table

Materials / Parameters	Forged Steel (AISI 4140)	Aluminum Alloy (A4032)	Gray cast iron
Max. value of total deformation (mm)	67.15	198.8	123
Min. value of von-mises stress (mpa)	0.09531	0.1071	0.09961
Max. value of von-mises stress (mpa)	4971	4965	4969
Max. value of Equivalent elastic strain (mm)	0.0247	0.07317	0.04525
Max. value of Buckling load (mm)	1.01	1.006	1.008

From static structural analysis, various parameters had been observed such as a total deformation, equivalent (von-mises) stress and Equivalent elastic strain, Buckling load of the connecting rod materials. By this, Forged steel (AISI 4140) is recorded the lowest deformation and also shows its behaviour with lowest equivalent (von-mises) stress. Among the three materials Forged steel (AISI 4140) is giving better results so, Forged steel (AISI 4140) is the best suitable material for connecting rod but when compare the density and weight property, carbon steel has high density value when compare to other material. To reduce the weight of the connecting rod we would like to perform topology optimization to reduce the weight and optimization of shape to improve the performance factors.

CONCLUSION AND FUTURE SCOPE:

This work investigated weight reduction and the suitable better material for minimizing deflections in connecting rod. First the connecting rod was designed. Load analysis was performed which comprised of the connecting rod, small and big ends of connecting rod using analytical techniques and computer-based mechanism simulation tools. Finite element anlysis (FEA) was then performed using the results from load analysis to gain insight on the structural behaviour of the I-section connecting rod and to determine the design loads for optimization.

The following conclusions can be drowned from this study.

There is considerable deference in the structural behaviour of the connecting rod between different materials. The different materials show different stress and strain values among the three materials Forged steel (AISI 4140) giving very less stress when compare to Aluminum Alloy (A4032) and Gray cast iron.

It is found that the connecting rod made of genetic Forged steel (AISI 4140) shows less amount of deflection and stresses and strain, buckling load than other material like Gray Cast Iron and Aluminum alloy (A4032) which are also studied in this study.

Among the three materials Forged steel (AISI 4140) is giving better results so, Forged steel (AISI 4140) is the best suitable material for connecting rod but when compare the density and weight property, Forged steel (AISI 4140) has high density value when compare to other material. To reduce the weight of the connecting rod we would like to perform topology optimization to reduce the weight and optimization of shape to improve the performance factors.

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