A REVIEW ON DESIGN AND OPTIMIZATION OF CONNECTING ROD

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ABSTRACT

The automobile engine connecting rod is a high volume production and critical component. Connecting rod is the intermediate link between the piston and the crank. And is responsible to transmit the push and pull from the piston pin to crank pin, thus converting the reciprocating motion of the piston to rotary motion of the crank. Generally connecting rods are manufactured using carbon steel and in recent days aluminium alloys are finding its application in connecting rod. In automotive engines, the connecting rod is subjected to high cyclic loads. These are represented by high compressive loads due to combustion, and high tensile loads due to the connecting rod mass of inertia. The main objective of this study is to review the weight optimization of a connecting rod in an automobile engine. To get the idea about designing the connecting rod, various stresses to be considered while designing the connecting rod and different materials used and comparing the result of all materials. To know the different software and Finite Element Method (FEM) packages useful for the modeling and analysis of connecting rod.

Keywords: *connecting rod, optimization, design*

1. INTRODUCTION

A Connecting rod is the link between the reciprocating piston and rotating crank shaft. Small end of the connecting rod is connected to the piston by means of gudgeon pin. The big end of the connecting rod is connected to the crankshaft. The function of the connecting rod is to convert the reciprocating motion of the piston into the rotary motion of the crankshaft. The connecting rods are usually forged out of the open hearth steel or sometimes even nickel steel or vanadium steel. For low to medium capacity high speed engines, these are often made of duraluminium or other aluminum alloys. However, with the progress of technology, the connecting rods these days are also cast from malleable or spheroid graphite cast iron. The different connecting rod steels are (4OC8, 37Mn6, 35Mn6 MO3, 35Mn6 Mo4, 40Cr4, 40Cr4 Mo3, 40NiCr4MO2) etc. In general, forged connecting rods are compact and light weight which is an advantage from inertia view point, whereas cast connecting rods are comparatively cheaper, but on account of lesser strength their use limited to small and medium size petrol engines.

It has mainly three parts namely- a pin end, a shank region and a crank end. Pin end is connected to the piston assembly and crank end is connected to crankshaft. A combination of axial and bending stresses act on the rod in operation. The axial stresses are product due to cylinder gas pressure and the inertia force arising on account of reciprocating motion. Whereas bending stresses are caused due to the centrifugal effects. To provide the maximum rigidity with minimum weight, the cross section of the connecting rod is made as and I – section end of the rod is a solid eye or a split eye this end holding the piston pin. The big end works on the crank pin and is always split. In some connecting rods, a hole is drilled between two ends for carrying lubricating oil from the big end to the small end for lubrication of piston and the piston pin.

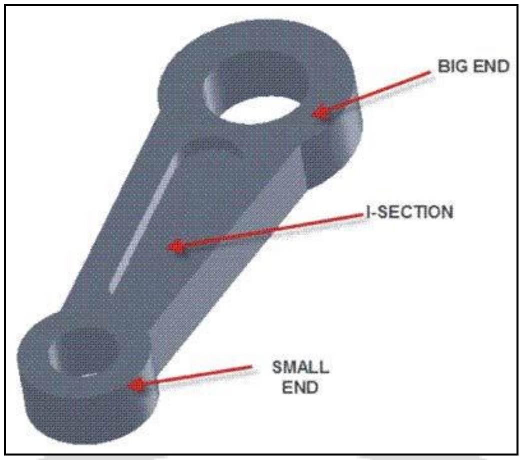

Fig- 1: Schematic diagram of connecting rod

A major source of engine wear is the sideways force exerted on the piston through the connecting rod by the crankshaft, which typically wears the cylinder into an oval cross-section rather than circular, making it impossible for piston rings to correctly seal against the cylinder walls. Geometrically, it can be seen that longer connecting rods will reduce the amount of this sideways force, and therefore lead to longer engine life. However, for a given engine block, the sum of the length of the connecting rod plus the piston stroke is a fixed number, determined by the fixed distance between the crankshaft axis and the top of the cylinder block where the cylinder head fastens; thus, for a given cylinder block longer stroke, giving greater engine displacement and power, requires a shorter connecting rod (or a piston with smaller compression height), resulting in accelerated cylinder wear.

The connecting rod is under tremendous stress from the reciprocating load represented by the piston, actually stretching and being compressed with every rotation, and the load increases to the square of the engine speed increase. Failure of a connecting rod, usually called throwing a rod, is one of the most common causes of catastrophic engine failure in cars, frequently putting the broken rod through the side of the crankcase and thereby rendering the engine irreparable; it can result from fatigue near a physical defect in the rod, lubrication failure in a bearing due to faulty maintenance, or from failure of the rod bolts from a defect, improper tightening or over-revving of the engine. Re-use of rod bolts is a common practice as long as the bolts meet manufacturer specifications. Despite their frequent occurrence on televised competitive automobile events, such failures are quite rare on production cars during normal daily driving. This is because production auto parts have a much larger factor of safety, and often more systematic quality control.

Finally, a shape optimization for connecting rod reduces the stresses over the entire rod. Due to its large volume production, it is only logical that optimization of the connecting rod for its weight or volume will result in large-scale savings. It can also achieve the objective of reducing the weight of the engine component, thus reducing inertia loads, reducing engine weight and improving engine performance and fuel economy.

2. LITERATURE REVIEW

There is a vast amount of literature related to Finite Element Analysis of shape optimization of connecting rod. Many research publications, journals, reference manuals, newspaper articles, handbooks; books are available of national and international editions dealing with basic concepts of FEA. The literature review presented here considers the major development in implementation of FEA.

Pravardhan S. Shenoy and Ali Fatemi (2005) [1] carried out the dynamic load analysis and optimization of connecting rod. The main objective of this study was to explore weight and cost reduction opportunities for a production forged steel connecting rod. Typically, an optimum solution is the minimum or maximum possible value the objective function could achieve under a defined set of constraints. The weight of the connecting rod has little influence on the cost of the final component. Change in the material, resulting in a significant reduction in machining cost, was the key factor in cost reduction. As a result, in this optimization problem the cost and the weight were dealt with separately. The structural factors considered for weight reduction during the optimization include the buckling load factor, stresses under the loads, bending stiffness, and axial stiffness. Cost reduction is achieved by using C-70 steel, which is fracture crackable. It eliminates sawing and machining of the rod and cap mating faces and is believed to reduce the production cost by 25%.

Fig- 2: The actual and the digitized connecting rods

The weight difference between the two when corrected for bolt head weight was less than 1%. This is an indication of the accuracy of the solid model. The engine configuration considered is tabulated in Table I.

Table I: Configuration of the engine to which the connecting rod belongs.

Crankshaft radius	48.5 mm
Piston diameter	86 mm
Mass of the connecting rod	0.439 kg
Mass of the piston assembly	0.434 kg
Connecting rod length	141 mm
Izz about the center of gravity	0.00144 kg m2
Distance of C.G. from crank end center	36.4 mm
Maximum gas pressure	37.3 Bar

For cyclic loading, safety factor of 1.66 on the endurable load amplitude for connecting rod. The same factor was used for the allowable stress amplitude here, and corresponds to a FI of 0.60. Similar to the case for axial loading, this assumed FI of 0.60 or the FI in the existing component, whichever was higher, was used for obtaining the allowable stress amplitude at a given location or region of the connecting rod. Fig 3 shows the FI distribution for the existing geometry with respect to the endurance limit of the existing material under cyclic load.

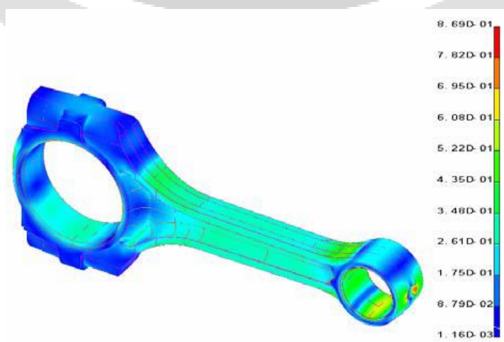

Fig- 3: Failure Index (FI), defined as the ratio of equivalent stress amplitude at R = -1 to the endurance limit of 423 MPa, for the existing connecting rod and material.

After several iterations, which involved determining the loads and performing FEA for the resulting geometry of each iteration step, an optimized geometry was obtained. Mass of the optimized connecting rod is 396 grams, which is lower than the mass of the original connecting rod by 10%. This geometry was found to satisfy the aforementioned design constraints. Fig 4 shows the FI distribution for the optimized connecting rod, for cyclic loading

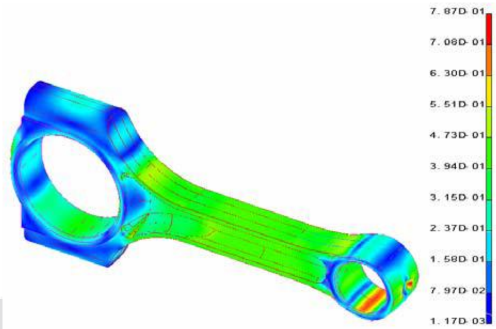

Fig- 4: Failure Index (FI) distribution for the optimized connecting rod.

The maximum von Misses stress is at the outer corners of rod-cap interface in Fig 5. Of the many nodes on the inner cap edge (at the rod-cap interface), the node with minimum radial displacement had a radial displacement value of 0.077 mm. This displacement is towards the center of the connecting rod bore. However, the clearance between the crank end bearing and the crankshaft is of the order of 0.026 mm for connecting rods in this size range.

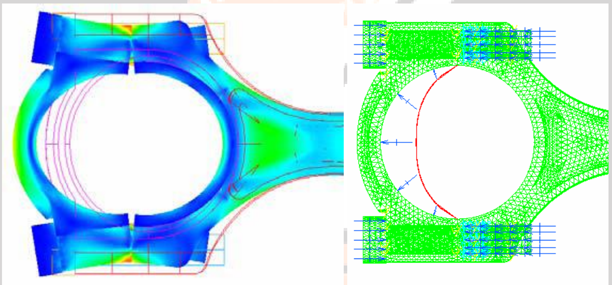

Fig- 5: Von Mises stress variation and displacements (magnified 20 times) of the connecting rod and cap under tensile load. The FE model is shown on the right.

The following conclusions can be drawn from the results of this study:

1) Fatigue strength was the most significant factor (i.e. design driving factor) in the design and optimization of the connecting rod.

2) Stresses and displacements were observed to be significantly lower under conditions of assembly (with bearings, crankshaft and piston pin and bushing), when compared to stresses obtained from unassembled connecting rod subjected to cosine loading.

3) The section modulus of the connecting rod should be high enough to prevent high bending stresses due to inertia forces, eccentricities, as well as crankshaft and case wall deformations.

4) The shank region of the connecting rod offered the greatest potential for weight reduction. The rib and the web thicknesses were reduced, while maintaining forge ability.

5) With using fracture splitting process, the two fracture split parts share a unique surface structure at the fractured surface that prevents the rod and the cap from relative movement, resulting in a firm contact. This increases the stiffness and reduces stress at critical locations in the crank end of the connecting rod.

6) The optimized geometry is 10% lighter than the current connecting rod for the same fatigue strength, in spite of lower yield strength and endurance limit of C-70 steel compared to the existing forged steel.

7) Reduction in machining operations achieved by using C-70 steel and utilization of the fracture splitting process reduces the production cost by about 25%. As compared with a PM connecting rod, the cost saving is estimated to be about 15%.

8) By using other facture crack able materials such as micro-alloyed steels having higher yield strength and endurance limit, it may be possible to further reduce the weight at the piston pin end and the crank end. Weight reduction in the shank region is, however, limited by manufacturing constraints.

Shahrukh shamim [2] studied finite element analysis of connecting rod used in single cylinder four stroke petrol engines. Static stress analysis is conducted on connecting rod made up of two different materials viz. E-glass/Epoxy and Aluminium composite reinforced with Carbon nano tubes. Modelling and comparative analysis of connecting rod is carried out in commercially used FEM software ANSYS 14.0. Static structural analysis was done by fixing the piston end and applying load at the crank end of the connecting rod. Output parameters in static stress analysis are von-Mises stress, Shear stress, total deformation and equivalent elastic strain for the given loading conditions.

The objective of this work is to develop solid model of connecting rod of single cylinder-four stroke diesel engine using ANSYS Design 14.0 software. Static structural analysis is performed using FEA software ANSYS 14.0. The materials used in this study are E-glass/Epoxy and Aluminium Nano composite reinforced with Carbon nanotubes. Output parameters of static structural analysis are von Mises stress, total deformation, shear stress and equivalent elastic strain.

The materials which are widely used in manufacturing connecting rod are carbon steel, Aluminium reinforced with Boron carbide. Connecting rods for automotive applications are typically manufactured by forging from either wrought steel or powder metal. The materials used in this study are E-glass/Epoxy and Aluminium composite reinforced with Carbon Nanotubes. Compositions of these materials are listed in table II.

Table II: Composition of E-Glass/Epoxy and Al-CNTs composite

Components	E-Glass	Epoxy
Composition (Vol. %)	40%	60%

Components	Aluminium	Carbon Nanotubes
Composition (Vol. %)	Al (Purity 99%, 200 mesh), 98%	MWCNTs, 2%

The FEA results for static analysis i.e. von-Mises stress, Total Deformation, shear stress and Elastic Strain are studied. From the results, comparison for the two materials is done. Table III shows the results of static structural analysis.

Table III: Results of static structural analysis

Parameters	FEA results of E-Glass/Epoxy	FEA results of Al- 2 vol.%CNTs composite	Variation
Equivalent von-mises stress	276.24 MPa	160.18 MPa	42.0%
Total deformation	1.48 mm	0.140 mm	90.5%
Shear stress	73.57 MPa	68.74 MPa	6.5%
Elastic strain	$2.96*10^{-2}$ mm/mm	$1.799*10^{-3}$ mm/mm	93.9%

Weight comparison of E-Glass/Epoxy and Al-2 vol. % CNTs composite used as connecting rod‟s material is shown in table IV.

Table IV: Weight comparison

Material	Weight
E-Glass/Epoxy	0.102 Kg
Al- 2 vol.% CNTs composite	0.0929 Kg

Solid modeling of connecting rod for four stroke single cylinder has been done using FEA tool ANSYS 14 workbench. On the basis of this study following conclusion has been made:

Maximum Von-Mises stress for E-Glass/Epoxy and Al-2 vol.% CNTs composite is 276.24 MPa and 160.18 Mpa respectively.

Connecting rod made from Al- 2 vol. % CNTs has less weight than that of E-Glass/Epoxy. Comparing the results obtained from the analysis for two different materials it has been found that the stress induced in the Al- 2 vol. % CNTs composite is less than the E-Glass/Epoxy.

G. Naga Malleshwara Rao [3] worked on Design Optimization and Analysis of a Connecting Rod. The main Objective of this work is to explore weight reduction opportunities in the connecting rod of an I.C. engine by examining various materials such as Genetic Steel, Aluminum, Titanium and Cast Iron. This was entailed by performing a detailed load analysis. Therefore, this study has dealt with two subjects, first, static load and stress analysis of the connecting rod and second, Design Optimization for suitable material to minimize the deflection. In the first of the study the loads acting on the connecting rod as a function of time are obtained. The relations for obtaining the loads for the connecting rod at a given constant speed of crank shaft are also determined. It can be concluded from this study that the connecting rod can be designed and optimized under a comprising tensile load corresponding to 360° crank angle at the maximum engine speed as one extreme load, and the crank pressure as the other extreme load. Furthermore, the existing connecting rod can be replaced with a new connecting rod made of Genetic Steel.

The buckling load (WB) may be calculated by using the following relations, i.e., WB = Max, gas force X factor of safety. The factor of safety may be taken as 5 to 6.

Note:

1. The I-section of the connecting rod is used due its lightness and to keep the inertia forces as low as possible especially in case of high speed engine. It can also withstand high gas pressure.

2. Sometimes a connecting rod may have rectangular section. For slow speed engines, circular cross-sections may be used.

3. Since connecting rod is manufactured by forging, therefore the sharp corners of I-section are rounded off as shown fig. above for easy removal of section from dies.

The values of deflections, maximum and minimum stresses for the different cases (applying forces at different areas) for different materials for element type solid92 and solid 95 are shown in the table V & VI respectively.

Table V: Deflections, maximum and minimum stresses using Solid-92

Solid92	*Genetic steel*			*Titanium*			*Cast Iron*			*Aluminum*		
	Dmx	Smx	Smn	Dmx	Smx	Smn	Dmx	Smx	Smn	Dmx	Smx	Smn
Case1	0.00173	21.839	0.00255	0.00329	21.264	0.00268	0.00344	22.933	0.00237	0.00512	21.092	0.00272
Case2	0.5107	400.295	0.03189	0.97258	397.826	0.06265	1.021	404.917	0.02384	1.513	397.202	0.63888
Case3	0.00389	37.902	0.00255	0.00741	36.315	0.00268	0.00774	38.394	0.00237	0.01153	36.068	0.00272
Case4	0.51058	399.437	0.05983	0.97258	397.826	0.03429	1.021	404.917	0.0464	1.513	397.202	0.35587
Case5	0.36318	285.951	0.09378	0.68329	285.799	0.01932	0.72603	290.728	0.08169	1.063	285.34	0.19396

Table VI: Deflections, maximum and minimum stress using Solid-95

S95	Genetic steel			Titanium			Cast Iron			Aluminum		
case	Dmx	Smx	Smn	Dmx	Smx	Smn	Dmx	Smx	Smn	Dmx	Smx	Smn
1	0.0017	21.77	0.002	0.0032	21.264	0.0026	0.0034	22.933	0.0023	0.005	21.092	0.002
2	0.5105	399.4	0.031	0.9725	397.82	0.0626	1.021	404.91	0.0238	1.513	397.20	0.638
3	0.0038	37.16	0.002	0.0074	36.315	0.0026	0.0077	38.394	0.0023	0.011	36.068	0.002
4	0.5107	399.3	0.032	0.9725	397.82	0.0342	1.021	404.91	0.0464	1.513	397.20	0.355
5	0.3632	285.8	0.090	0.6832	285.79	0.0193	0.7260	290.72	0.0816	1.063	285.34	0.193

This work investigated weight reduction and the suitable better material for minimizing deflections in connecting rod. First the connecting rod was digitized. 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. FEA was then performed using the results from load analysis to gain insight on the structural behavior of the connecting rod and to determine the design loads for optimization. The following conclusions can be drawn from this study.

• There is considerable deference in the structural behavior of the connecting rod between axial fatigue loading and static loading. There are also differences in the analytical results obtained from fatigue loading simulated by applying loads directly to the connecting rod.

• Bending Stresses are significant and should be accounted for tensile bending stresses are about 266.86333 N/mm2

• In this FEA, the two model analysis Solid 92, Solid 95 is used to estimate the bending stresses and deflection. From this study, it is found that solid 95 gives accurate measurements of stress compared to Solid 92

• It is also found that the connecting rod made of genetic steel shows less amount of deflection and stresses than other material like Titanium, Cast Iron and Aluminum which are also studied in this study.

T Chandra Sekhar, CH Joseph Sundar, MP Manmohanan [4] investigated and compares fatigue behavior of forged steel and powder metal connecting rods. At the same time comparing cost analysis of both the materials like forged steel and powder material are compared. They must be capable of transmitting axial tension and compression loads. For applying tension and compression loads we are using latest solver technology called Altair Hyper works software. In which we have Altair Hyper mesh for preprocessing, Altair Radios for solving tension and compression analysis at the same time fatigue analysis for checking the life of two different materials based on tension and compression condition are solved. Final conclusion is based on the result of which material is having more life. Based on cost of the two different materials, which will be low cost so that which material connecting rod can be more applicable.

Tension and compression loads were applied as pressure on the bearing surfaces of the connecting rod. Under actual service condition, pin end experiences tension by the piston pin causing distribution of pressure along the upper half of the inner diameter, which is approximated by the cosine function. In compression, the piston pin compresses the bearings against the pin end inner diameter, causing uniform distribution of pressure.

In this study, first a literature review on several aspects of connecting rods in the areas of load and stress analysis and cost analysis. Forged steel and powder metal connecting rods were then used to obtain and compare the fatigue properties and behaviors. Experimental results and observations, and analysis performed, the following conclusions can be drawn:

1. Results of tensile and compressive test of connecting rod, which shows clearly that forged steel has 20% more life then the powder metal connecting rod.
2. As per fatigue test for both powder material and forged steel, forged steel life shows 1E20 cycles and for powder metal connecting life is 1E16 cycles. There is different of 20% compare to forged steel. By this it has been proved that forged steel is better replacement on powder metal.

3. A major reason for the increased use of powder metal connecting rods has been its cost effectiveness. Some automotive manufacturers are starting to switch back from powder metal to forged steel connecting rods, due to their higher fatigue life which ranges 1E20 cycles and reasonable manufacturing process cost of rupees 290.51
4. From tensile tests and monotonic curves it is concluded that forged steel is considerably stronger than the powder metal. Yield strength of forged steel is 16% higher than that for the powder metal. Ultimate tensile strength of forged steel is 8% higher than that of the powder metal.

Hitesh Kumar, Vijay Kumar Sharma studied to do analysis of connecting rod and get idea of stress producing compressive loading. And then give idea about weight reduction opportunities in connecting rod of an I.C. engine by examining two materials, AISI 1040 carbon steel and AISI 4340 alloy steel. This has entailed performing a detailed load analysis. Therefore, this study has deal with two subjects, first, static load and stress analysis of the connecting rod and second optimization for weight reduction and shape. In this project a static analysis is conducted on a connecting rod of a single cylinder 4- stroke petrol engine. In this project, a connecting rod for I.C. engine was designed by analytical method. On the basis of that design a physical model was modeled in Pro-E (creo parametric 2.0). Structural system of connecting rod has been analyzed using FEA. With the use of FEA von-misses stress, strain, shear stress, deformation, and weight reduction etc, were calculated for a particular loading conditions using FEA Software ANSYS WORKBENCH 14.0. The same work was done on the same design for other different materials. Compared to the former material the new material found to have less weight, stress reduction and better stiffness. After that based on results AISI 4340 alloy steel connecting rod are better than AISI 1045 carbon steel rod.

The objective of the present work is to design and analysis of connecting rod made of AISI 1045 carbon steel and AISI 434 alloy steel. In this project, the first two forces have been considered. In this project, a connecting rod for I.C. engine is design by analytical method. Carbon steel material and alloy steel material is used to design the both connecting rods. Connecting rod was created in Creo Parametric2.0. Model is imported in ANSYS 14.0 for analysis. Analysis is done for a given load condition. In this project, load condition is gas force (compressive load), which is also known s static load. After analysis a comparison is made between AISI 1045 carbon steel connecting rod viz., AISI 4340 alloy steel connecting rod in terms of various stress, strain, total deformation, weight, shape optimization. In this project AISI 1045 carbon steel connecting rod is replaced with AISI 4340 alloy steel connecting rod.

Stress, total deformation and elastic values are shown in below table.

Table VII: Stress, total deformation and elastic values

parameters	AISI 1045 carbon steel		AISI 4340 alloy steel	
	min	max	min	max
Equivalent stress (MPa)	2.3446e-002	117.41	2.1181e-002	117.22
Shear stress(MPa)	-35.007	35.075	-34.872	35.053
Normal stress(MPa)	-112.72	18.247	-112.46	18.022
Max. principal stress (MPa)	-31.476	36.424	-31.057	36.103
Total deformation(mm)	0	.02457	0	.023418
Elastic strain	1.2239e-007	.00059549	1.2052e-7	.00056634

The structural analysis and shape optimization on the connecting rod using two materials AISI 1045 Carbon steel and AISI 1045 alloy steel has been done and comparing both connecting rods results and is concluded that –

1. The maximum stresses occurred in static structural analysis are less than the yield strength of material. Hence the design is safe.

2. Maximum stresses occurred at the piston end of the connecting rod and minimum stresses occurred at crank end of connecting rod.

3. By comparing the stresses values for both materials, it is slightly less for AISI 4340 alloy steel than AISI 1045 carbon steel.

4. The AISI 4340 alloy steel connecting rod is comparatively much stiffer than the AISI 1045 carbon steel connecting rod.

5. Weight can be reduced by changing the material of the current AISI 1045 carbon steel connecting rod to AISI 4340 alloy steel.

6. By using AISI 4340 alloy steel instead of AISI 1045 carbon steel can reduce weight up to .25%

7. According to shape finder tool, AISI4340 alloy steel connecting rod is lighter than the AISI 1045 carbon steel connecting rod.

By observing the results, authors concluded that AISI 4340 alloy steel connecting rod is better than AISI 1045 carbon steel connecting rod.

3. CAE TOOLS AND SOFTWARE

Computer-Aided Engineering (CAE) is the broad usage of computer software to aid in engineering tasks. It includes computer aided design (CAD), computer aided analysis (CAA), and computer integrated manufacturing (CIM), and computer aided manufacturing (CAM), material requirements planning (MRP) and computer-aided planning (CAP). CAE embraces the application of computers from preliminary design (CAD) through production (CAM). Computer Aided Analysis includes finite element and finite difference method for solving the partial differential equations governing solid mechanics, fluid mechanics and heat transfer, but it also includes diverse program for specialized analyses such as rigid body dynamics and control system modeling. Recently, manufactures have been asked to design their products for eventual recycling, and this aspect of engineering will undoubtedly fall under the umbrella of CAE, but as of yet it doesn't have its own acronym. CAE tools are being used, for example, to analyze the robustness and performance of components and assemblies. The term encompasses simulation, validation, and optimization of products and manufacturing tools. In the future, CAE systems will be major providers of information to help support design teams in decision making.CAE areas covered include:

1. Stress analysis on components and assemblies using FEA (Finite Element Analysis);

2. Thermal and fluid flow analysis Computational fluid dynamics (CFD);

3. Kinematics;

4. Mechanical event simulation (MES).

5. Analysis tools for process simulation for operations such as casting, molding, and die press forming.

6. Optimization of the product or process.

4. CONCLUSIONS

Above all researchers gives the idea about designing of the connecting rod. It explains about the various stresses to be considered while designing the connecting rod and different materials used and comparing the result of all material. Also most of the researchers used the CATIA software for the modeling and ANSYS software for analysis. These can be used for designing any connecting rod in Automobile. Connecting rod can be designed for weight and cost reduction also to increase the life time of connecting rod. Upto some level of extent the weight of the connecting rod is lighter and having more strength as compared to the original design.

5. FUTURE SCOPE

- Designing a connecting rod for a specific two wheeler IC Engine, by numerical method.
- The connecting rod can be further modified with suitable alternate material for weight optimization.

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