Parameters influencing connecting rod: A Review

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Abstract— Connecting rod works as an intermediate link between piston and crankshaft. The function of connecting rod is to convert reciprocating motion into rotary motion. Since it is subjected to variable tensile and compressive load, it should be strong enough to bear that load. Manufacturing of connecting rod is one of the most important parameter that can affect the overall performance of connecting rod. Selection of connecting rod for good performance of engine is very difficult. There are various factors that are to be considered before selecting connecting rod, like type of engine, maximum rpm engine produces, requirement of relative weight, stiffness and strength of connecting rods, type of cross section like I-section, H-section, Rectangular or circular, material of connecting rod etc. After selecting the appropriate cross section, the material used in the connecting rod should be chosen wisely because during manufacturing process it has to undergo various production processes and subsequent heat treatment process, which is very much important for strength and stiffness. In this paper, a review has been attempted on selection parameter of connecting rod like cross section, manufacturing process and material selection which can enhance the performance of engine.

Index Terms— Connecting Rod, ANSYS, Optimization, Material, Review

1 INTRODUCTION:

Every engine uses connecting rod to convert reciprocating motion of piston into rotary motion of crankshaft. Connecting rods small end is connected to piston pin and big end is connected to crankpin. Connecting rods are available in various sections like I-section and H-section. Generally I-section is preferred mostly. Its strength and stiffness can be increased by changing its section or by changing some parameters of connecting rod. By changing the material of the connecting rod weight and cost can also be reduced. However stress analysis of connecting rod can be done by using ANSYS.

Connecting rod can be manufactured by various processes. Approximately 20 to 40% of material of original work piece is wasted in flash when connecting rods are manufactured by hot forging. So in order to avoid wastage of material, the forging should be flash less i.e. it should be manufactured in closed cavity [1]. For heavy vehicles, to enhance the performance of connecting rod, good mechanical properties are required. Mechanical properties do not meet the requirement when connecting rod is quenched in oil. But when it is quenched in aqueous polymer water apparently mechanical properties enhances but there are chances of cracks to be appearing in connecting rod [2]. It can also be manufactured by powder metallurgy process.

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This process enhances the microstructure and the mechanical property of connecting rod. In place of steel, if titanium alloy is used to manufacture connecting rod by this method then tensile strength and elongation of connecting rod can be increased to a greater extend [3]. Studies show that due to high stress and pressure near web and flange of connecting rod causes noise and vibration in the engine. This can be significantly reduced by modifying the design of connecting rod [4]

2 CLASSIFICATION OF CONNECTING ROD

Connecting rods can be broadly classified on the basis of three major parameters like cross sectional area, manufacturing technology and selection of material.
On the basis of cross sectional area connecting rods are as follow:

1. I-section
2. H-section
3. Rectangular section
4. Circular section

On the basis of production method connecting rods are as follow:

1. Forging
2. Casting
3. Powder Metallurgy

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On the basis of material connecting rods are as follows:

1. Alloy
2. Composite

3 CONNECTING ROD DESIGN ON THE BASIS OF CROSS SECTION

The design has great impact on connecting rod strength. Connecting rod can be designed of various cross sections and summary is shown in Table 1.

Table 1. Results of optimised design of connecting rod

Author name	Optimised Design	Results
Dantale, A.D., and A. J. Keche [6]	Modification of cross section at the big end location	Fatigue life of connecting rod was observed.
Doshi, N.P., and .N.K. Ingole [20]	Comparision between production design of connecting rod and connecting rod designed via. Machine design approach	Possibility to reduce mass of connecting rod.
Roy, B.K. [5]	Increase in fillet radius of connecting rod	Design is safe with good fatigue life.
Pal, S., and S.kumar [21]	Removed material from connecting rod	Weight of connecting rod is reduced.
Khare, S., O.P. Singh , K. B. Dora, and C. Sasun [4]	The beginning area of the flange and end area of the web of the I-section of the connecting rod is enlarged.	Maximum Pressure and von misses stress has been reduced.

The most common shank area of connecting rod is I-section. This section is generally preferred because it increases the strength of connecting rod and decreases the overall stress on connecting rod. To reduce the pressure impact and stress at connecting rod a spalling investigation was done. This investigation is done on engine dynamometer. First of all various modes of failure are calculated and then correlated with connecting rod. Then vehicle is made to run on dynamometer at various speeds. The noise of engine was 90Db, the engine failed and connecting rod was checked for spalling investigation. When failed sample was checked for spalling investigation the clearance between connecting rod and crankpin was 15 mm that was not matched with specified design and decrease to 12 mm as shown in Figure 1. This changed design decreased the maximum pressure up to 33.70% and decreased the von misses stress up to 15.60% [4].

Connecting rod is subjected to various stresses that are caused due to friction of piston ring piston, inertia of connecting rod etc. These stresses Caused changes in various parameters of connecting rod. In this paper, structural analysis is carried out to find out suitable design parameter for connecting rod. The result of both existing and new connecting rod is compared. The changes are made in various parameters of connecting rod that reduces engine weight, inertia load and increases fuel efficiency. The analysis of design of connecting rod is done using finite element method. First the model was prepared in CATIA and imported to FEM, and then various analyses were done on new design of connecting rod. This has been found that the design is safe and stresses are also safe [5].

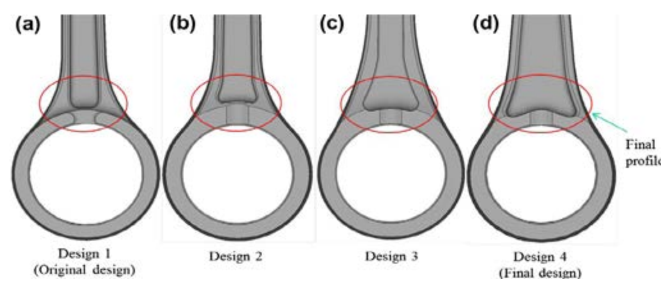

Fig. 1 Four different web designs of connecting rod

There are mainly two types of cross section of connecting rods i.e. I-section and H-section. Mostly used cross section of connecting rod is I-section because it has good strength and it also reduces weight of connecting rod. It provides good tensile strength; also it can support high compressive loads. But when it comes to Compaq handling it thickness and strength of, material limit this ability. So, because of this reason the cross section of I- beam is made thicker in some area to make it stronger and also material of high

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tensile and compressive strength is used.

In case of H- section the design is completely different. In H-section there are two large flat sides, having thin section in middle and perpendicular to journal of crankshaft and piston pin. Because of this geometry the stiffness of connecting rod increases due to this it does not bend during high compressive load.

The different sections of connecting rods are used as per the function of engine and requirement of design parameter. The fatigue life of connecting rod is tested by modifying its design. And the validation of results is done experimentally.

First the 3D model is developed and meshing is done. In this meshing connecting rod is treated as single part. During this analysis, the test were conducted on two ways firstly load is applied on big end by keeping the small end fixed and then load is applied on small end by keeping the big end fixed. The force applied is assumed to axially compressive. After analysis it is seen that highly stressed area in connecting rod in both cases is near big end of connecting rod as shown in Figure 2. Even after heat treatment and by setting connecting rod crack free the highly stressed region is big end of connecting rod compared to other section. Because of this high stress, the cross section area of this location is needed to be modified. The results of modified section have good fatigue life and also the new design of connecting rod is safe [6].

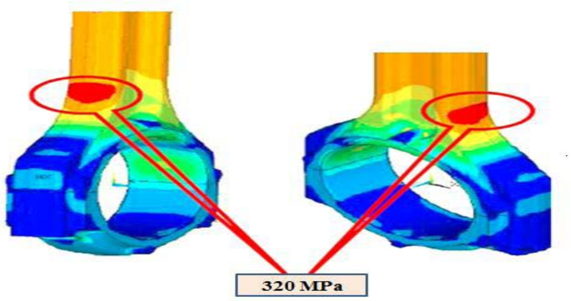

Fig. 2 Highest Stress Location at Big End of Connecting Rod

4. MANUFACTURING OF CONNECTING ROD

Connecting rod is subjected to high inertia forces. Light weight connecting rod with high fatigue strength can reduce these forces with high fatigue strength. There are various types of manufacturing processes, that are use to design connecting rods. Before selecting any manufacturing process, the economic, the technical and quality constraints are applied. In economic constraint, it involves cost of raw material. In technical aspect, it involves minimum weight of connecting rod. Quality aspect involves tolerances etc. There are basically three types of production method casting, forging and powder metallurgy. Out of which powder metallurgy method is more expensive because it has high capital cost. Connecting rod manufacturing is a high volume production which involves precise design and good performance.

4.1 Casting

Connecting rods are mainly manufactured by wrought process and powder metallurgy. There is great increase in manufacturing of connecting rod by powder metallurgy process. The manufacturing cost of connecting rod by powder metallurgy process is economic compare to other process. Light weight connecting rods are highly in demand due to its reduced weight and cost effectiveness. For such light weight, titanium can be preferred.

In this process, first sintering of titanium alloy is done in a furnace at 1300c. Then die forging is done at 1000c. After this extra flash is removed from die and annealing is done at 600c for 2h. After this structural examination of connecting rod is done fluorescent detection method, again annealing is performed at 600c and then machining of connecting rod is done. The mechanical properties of titanium alloy connecting rods are then compared with PF-11C50/60 and it is concluded that yield strength of powder metallurgy connecting rods are greater than those of PF-11C50/60 material [3].

Another process of manufacturing connecting rod is liquid die forging. The material used in this process is aluminum alloy. This method replaces die casting and hot die forging. In hot die forging, it requires great machining allowance and material utilization was also less. These factors affect the cost of production. To overcome these losses, liquid die forging process is introduced. The aluminum alloy used in this process is ZL202. When the manufacturing is done it has been seen that the structure of metal is homogeneous and fine grain. This increases the quality of product. The die used for this process is simple and compact which reduces its cost. It has been analyzed that forging cost is reduced up to 30-35% than old technology [7].

4.2 Forging

There are two common methods to manufacture connecting rods i.e. steel forging and powder forging. Both processes have advantages and disadvantages.

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The analysis of connecting rod is done in 3 ways: first to determine compressive load on connecting rod kinematic, dynamic and thermodynamic study is performed. In second step we apply load on various location of connecting rod. In third step, comparison for fatigue strength is done between steel forged and powder forged connecting rods. After these three analyses are performed it has been seen that compressive and tensile strength of steel forged connecting rod is much more than that of powder forged connecting rod.

In early 90's, all passengers cars used to have steel connecting rod. Because of their heavy weight it has been tried to replace steel with some lighter material. The attempt was made to replace steel with aluminum composite but because of their less strength and high cost it was not successfully implemented. But aluminum composite connecting rod can be manufactured at economic cost by flash less forging. The only disadvantage is that design of this forging is very complex as compare to close die flash forging. So in order to reduce this complexity, finite element method is used. In forging process flow of metal takes place in 3d stress and strain. The connecting rod is designed by forging method and 3d analysis is performed separately in different parts of connecting rods. From result it is concluded that optimization of this part is difficult from other parts, because of its complex geometry. In this process of manufacturing connecting rod, it is concluded that the small end section can be easily formed [1].

Forging is one of the most common processes to manufacture connecting rods. The connecting rods produce in several stages by forging. The material used in the production of connecting rod has to be performed by stretch rolling before fabricating the connecting rod. Preformed of material is done for better die filling, maximum material flow and proper material utilization. After preformed of connecting rods, material die forging is done in two steps (pre and final forging is finished, extra flash is removed from the die and it is kept at room temperature for cooling. This process is called forming process and temperature of work piece is measured. The work pieces after forming process are shown in Figure 3. Now microstructure and mechanical properties of work pieces are tested. After this several process are employed to manufacture connecting rod. After manufacturing it is concluded that surface temperature and geometry of work piece are close to reality [9].

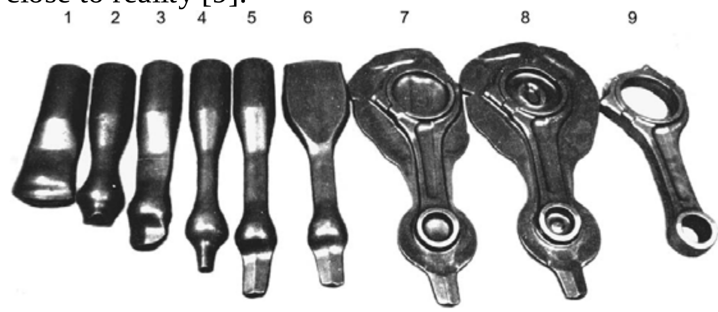

Fig. 3 Workpieces after forming stages 1–9 (from left toright). 1–5: stretch-rolling, 6: flattening, 7,8: die-forging, 9: flash removal and hopunching

4.3 Powder metallurgy

In powder forged manufacturing process the connecting rod is solidify metal powder into pre shape which is sintered. Then it is heated up to forging temperature till it gets completely dense to get final shape. After this the work piece is machined to final dimension. In powder forging process material quickly get dense. This process is to manufacture connecting rods where high strength and durability are required. The first step involve in this process is to cool the powder metal till it get shape close to final forged shape. This final forged shape is then heated at a controlled temperature in a furnace. The main advantage of this process is that material doesn't waste as in case of forging process in which material wastes in the form of flash. Another advantage is that re-heating is not required after forging. Also it requires less temperature as compare to conventional forging. The steps involved in powder metallurgy process are shown in Figure 4 [10].

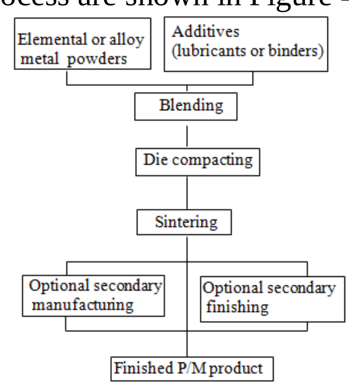

Fig.4 Steps involved in powder metallurgy process

5. MATERIAL USED IN CONNECTING RODS

There are some materials that are commonly used in connecting rods such as alloys of steel, aluminum and titanium. Mostly connecting rods are made by forged

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steel. It is widely use because it has high tensile and compressive strength. There are large varieties of steel alloy that are used to manufacture connecting rod. All alloys can have different property because of heat treatments. Sometimes, mixture of different materials can also be used such as aluminum and titanium.

Titanium is used in making connecting rods, since very long time but when it comes to lightweight of connecting rod, aluminum is preferred. Titanium is the most costly material among steel and aluminum. Another demerit of titanium is their fatigue life. Aluminum is also used for a long time.

5.1 Alloys

Most of the connecting rods are made of steel but aluminum can also be used to manufacture connecting rods because of its light weight and it can also absorb high impact shock but its durability will be suffered. Titanium can also be used because it has good strength but it is expensive. Different materials like aluminum alloy 6061, aluminum 7075 are used in place of forged steel. First of all connecting rod is modeled in proE software. Ansys software is use for testing the material for stress and strain. The model of connecting rod was analyzed for displacement, von misses stress etc as shown in Figure 5. After analysis result, it has been seen that stresses on aluminum 6061, aluminum 7075 are within the limit. Therefore, steel connecting rod can be replaced with aluminum alloy for lighter and better performance [11].

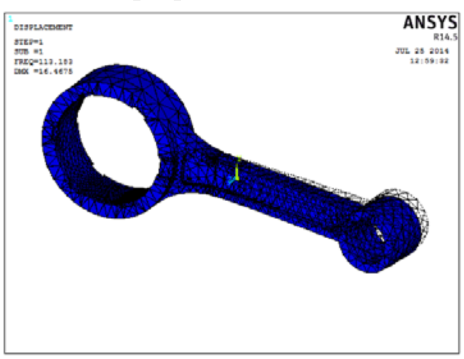

Fig.5 Analysis of aluminium alloy connecting rod

The comparison between steel forged connecting rod and powder forged connecting rod is done for better fatigue strength. The 3D model of connecting rod was designed in Pro/E software as shown in Figure 6.

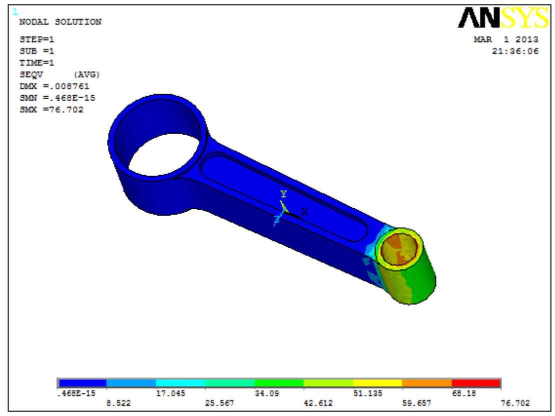

Fig. 6 3D Model of connecting rod

When the existing material of connecting rod i.e. carbon steel is replaced with aluminum 360 it has been found that the weight of aluminum 360 connecting rod is 4 times lighter than carbon steel. It is because density of Al360 is very less compared to carbon steel [12]. Stress analysis of aluminum connecting rod was performed by dynamic simulation. First of all, the measurements of connecting rod were taken and then the model of connecting rod was drawn in CATIA software in IGES format. The dynamic simulation of connecting rod was performed by finite element analysis using ANSYS. In Finite Element Analysis, the load is applied in operating condition. The result shows that maximum deformation occurs at small and big end bearing as shown in Figure 7. Because of maximum deformation in this area the fatigue crack is likely to appear in these areas [13].

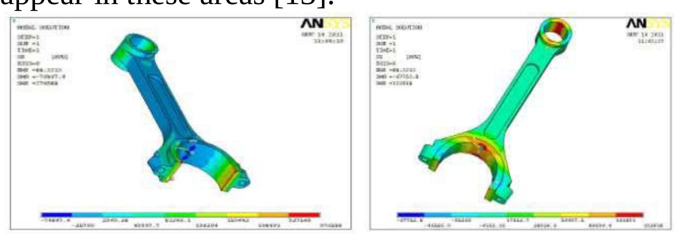

Fig. 7 Stress field in X and Y direction

Now day's aluminum alloys are replacing carbon steel connecting rods. Von misses stress and total deformation of forged steel is compared with two aluminum alloy. All the analysis is done by finite element method using ansys. 3D model of connecting rod is designed and imported to ANSYS. Meshing is done in ANSYS. Static structural analysis is performed. Various parameters like deformation , von misses stress are calculated for three material viz. forged steel, Aluminum 6061-T6 and aluminum 5083. It is found that stresses of all three materials are in safe limit. There is reduc-

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tion in weight of AL5083 connecting rod i.e. forged steel can be replaced with Al 5083. The weight of connecting rod reduces by 63.19% [14].

A comparison is done among various material of connecting rod like genetic steel aluminum titanium and cast iron for weight reduction. It was performed by load analysis. In this work, first various forces acting on the connecting rod has been considered like inertia and bending forces as shown in Figure 8.

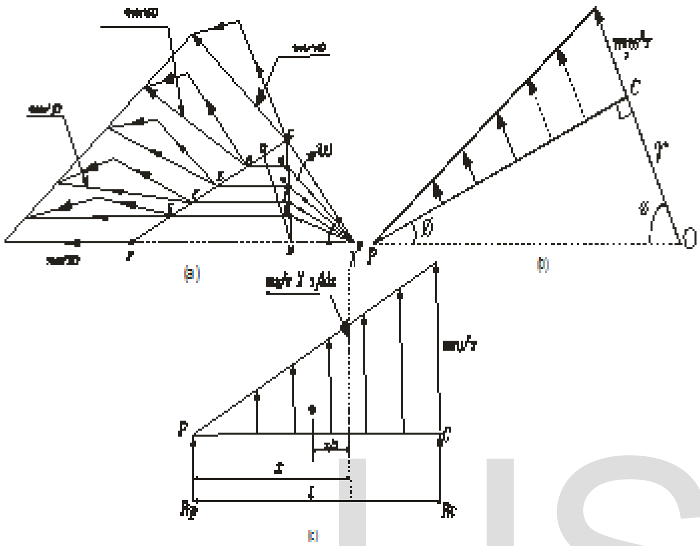

Fig. 8 Inertia and bending forces

After this various parameters of connecting rod are calculated to design connecting rod. Then model of connecting rod is prepared using Pro-E software. The model of connecting rod is imported to ANSYS form Pro-E. Solid 92 and solid 95 elements are chosen in ANSYS. After this meshing of connecting rod is done. Load is applied on big end of connecting rod. After load application solution is done to obtain various results like von misses and total deformation. This analysis is repeated for each material. From results it has been concluded that genetic steel connecting rod has less stress and deflection as compare to titanium, cast iron and aluminum [15].

The steel connecting rods can be easily replaced with aluminum alloy connecting rod where weight is the major concerned because connecting rod of aluminum alloy is lighter in weight than that of steel connecting rod. The alloys that are used to replace AISI 4340 is AL7068. First of all design parameters of connecting rods are calculated numerically. The cross section of connecting rod is I –section. These parameters are used in pro-E for 3D modeling of connecting rod. Load is applied in two condition, first load is applied at crank end and other end is kept load free and secondly load is applied at piston end keeping other end is load free. Now, analysis is performed in ANSYS workbench 12.0. Weight can be reduced up to 63.95% using Al 7068 alloy in place of AISI 340. Also stress in Al7068 is less by 3. 59% [16].

5.2 Composites

Connecting rod of four stroke single cylinder engine is used for making comparison between conventional orthotropic and isotropic material using finite element analysis. The isotropic material is of steel and it is compared with orthotropic composite material (E-Glass/E-Poxy). Fem analysis of connecting rod is performed to calculate von misses stress and total deformation as shown in Figure 9.

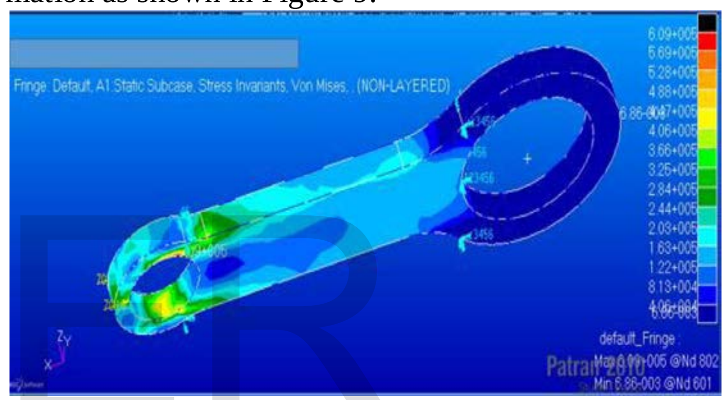

Fig. 9 Von misses stress calculation

Also linear static analysis is performed to get different results using MSC PARTAN for steel and for E-Glass/E-Poxy. CATIA V5 software is use to design connecting rod. In this analysis, load constraint and displacement constraint are used. In displacement constraint big end is kept fixed and small end is kept free in Y- direction only. In load constraint, load of 700n is applied in small end. After applying load and displacement constraint analysis is performed. Results shows that stresses are reduced to 33.99% when E-Glass/E-Poxy is used. Reduction in displacement is noted to be .0026% in case of E-Glass/E-Poxy. The result shows the conventional steel can be replaced with E-Glass/E-Poxy [17].

Different types of materials can be used in manufacturing connecting rods. Mostly used material is aluminum alloy and aluminum composite because it provides weight reduction in connecting rod than conventional steel .There are many kinds of aluminum composited that are available. Aluminum reinforced with silicon carbide can also be used to manufacture connecting rods. The analysis of Aluminum alloy connecting rod. For creating a 3D model of connecting rod PRO- E software is used for performing static analysis ANSYS 14.5 workbench is used. Different loading condition will be applied at small end and big end of connecting rod.

In this work Aluminum alloy 5083 is used which is later reinforced with silicon carbide. The process used in the fabrication of this composite is ultrasonic assisted stir casting process. When the model is designed in PRO-E it is imported to ANSYS. Load is applied by keeping big end fixed and applying pressure at small end. Pressure applied is of 1.4 Mpa. Parameters like equivalent stress, maximum shear stress; total deformation etc. is analyzed for both materials. When the result for both the material are compared, it has been found that weight of aluminum composite is 1/3 times lighter than that of steel. The value of von misses stress is less in aluminum alloy. Thus aluminum composite connecting rod can be replaced with existing steel connecting rod [18].

Another composite that can be used to manufacture connecting rod is aluminum fly ash. Experimental test and spectrometer test are performed to check its strength and stability against steel connecting rod. Also analysis of aluminum composite connecting rod is performed in ANSYS. The material used as a composite is aluminum Lm6.

It has good corrosion resistance property and ductility. This material is reinforced with fly ash which is finely divided residue of pulverized coal. Both aluminum alloy and fly ash are first heated in a crucible furnace and then mixed together in the ratio of 5:1.

When tensile and compression test is performed in both the connecting rod, the results were nearly same. Their hardness number is also same. When weight of both connecting rod materials is compared, it is seen that aluminum composite is lighter than steel connecting rod. Weight reduction up to 50% is achieved [19] and summary of different materials is shown in Table 2.

Table 2. Results of different materials when replaced with existing material

Author name	Existing material	New material	Results
Fegade,V.T., and K. S. Bhole [22]	Forged steel	Forged steel+titanium	Titanium increases the strength and stiffness of shank region.
Lohan, N., and S.Nandal [23]	steel	Aluminium composite	High strength with unit cost reduction of connecting rod.
Venkatesh, S., I.B. Clement, C. A. Kumar, D.B. Raja, and S. Anand [19]	Steel	Aluminium reinforced with fly ash	New connecting rod is 50% lighter than existing connecting rod
14)Savanoor, R.A., A. Patil, R. Patil ,and A. Rodagi [14]	Forged steel	Aluminum alloy	AL5083 is 63.19% lighter in weight.
Ahmed, G.M.S., S. E. Khany, and S.H. Shareef [11]	Forged steel	Aluminium composite and carbon fibre.	The aluminium 7075 and carbon fibre connecting rod are the best to be used as they with stand the forces
Idrisi,A.M., and S. Roy [18]	Steel	aluminium alloy reinforced with sic	Stresses in aluminium alloy connecting rod are less compared to exiting material.
Vegi, L.K., and V.G. Vegi [24]	carbon steel	Forged steel	Forged steel connecting rod has more stiffness and less stress than carbon steel connecting rod.
HariPriya ,M., and, K.M. Reddy [12]	Forged steel	Al360	The stress value of aluminum connecting rod is less than steel cconnecting rod.

6. Conclusions

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Connecting rod is one of the most important parts of IC engine. Connecting rods are available in various cross sections. The selection of right cross section of beam mainly depends upon the type of engine and manufacturing process. I cross section beams are easy to design by forging process but it is bit heavier than H cross section beams. H cross section beams are preferred where light weight connecting rod is required.

Connecting rod can be manufactured by using different manufacturing processes depend upon its area of application. Different manufacturing processes affect the working of connecting rod. The most important factor that has to consider during the production of connecting rod is its material selection. There are various types of materials that are used for manufacturing connecting rod. Every material has its own strength and ability. From various research works it has been found that:

1) Depends upon the rpm of engine, for high rpm I-beams can be used and for low rpm heavy H-beam will be suitable.

2) A- beam and X- beam are also used but their application is limited because of their heavy weight and low strength.

3) Modification of design parameters of cross section helped to increase the fatigue life of connecting rod, reduce the weight of connecting rod and it helped to reduce the stresses.

4) Strength and stiffness of connecting rod improved by replacing existing forged steel or steel material with alloy or composites. It also helped to reduce the values of stresses and it is cost effective.

7. Future scope

After reviewing various selection parameters of connecting rod it has been seen that there is wide scope of research to explore this research work. More and more advance hybrid material can be used to manufacture connecting rod that will not only make it lighter but will also reduce its cost. Also modern manufacturing technologies can be developed that can reduce the time of manufacturing and make it possible to design some critical parts of rod with an ease.

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