DESIGN OF INLINE-FOUR CYLINDER GASOLINE ENGINE AND ANALYSIS OF PISTON, CONNECTING ROD AND CRANKSHAFT

E. Prakash , R. Sabarinathan , R. Sankaranarayanan , M. Dinakaran

Abstract — The inline-four cylinder engine or straight-four engine is an internal combustion engine with all four cylinders mounted in a straight line, or plane along the crankcase. The cylinders may be oriented in either a vertical or an inclined plane with all the pistons driving a common crankshaft, where it is inclined it is sometimes called a slant-four. In a specification chart or when an abbreviation is used, an inline-four engine is listed either as I4 or L4.

This engine consists major elements like piston, connecting rod, camshaft, crankshaft, valves, crank case, water pump, scavenge pump, alternator, engine head, cylinder block and sump.

The main objective of our project is to develop the model of inline-four cylinder engine by using **Creo parametric software.** The elements that are developed in Creo parametric and subjected to Static analysis by comparing original material Grey Cast Iron (Fe40) with alternate material Aluminium Alloy (Al6061) using simulation tool in order to reduce the weight.

***Keywords* --** Four inline engine, creo parametric, piston, value, connecting rod, crankshaft, camshaft, simulation.

I. INTRODUCTION

An internal combustion engine is defined as an engine in which the chemical energy of the fuel is released inside the engine and used directly for mechanical work, as opposed to an external combustion engine in which a separate combustor is used to burn the fuel. The internal combustion engine was conceived and developed in the late 1800s. It had a significant impact on society, and is considered one of the most significant inventions of the last century. The internal combustion engine has been the foundation for the successful development of many commercial technologies. The overwhelming majority of burning engines are created for conveyance applications, requiring an influence output on the order of 102KW. Next there to burning engines became the dominant cause technology in many areas. For instance, in 1900 most vehicles were steam or electrically power driven, however by 1900 most vehicles were power-driven by fuel engines. Since 1970, with recognition of the importance of air quality, there has conjointly been an excellent deal of labor dedicated to reducing emissions from engines.

Inline Four Cylinder Engine:

The inline-four engine or straight-four engine is an internal combustion engine with all four cylinders mounted in a straight line, or plane along the crankcase.

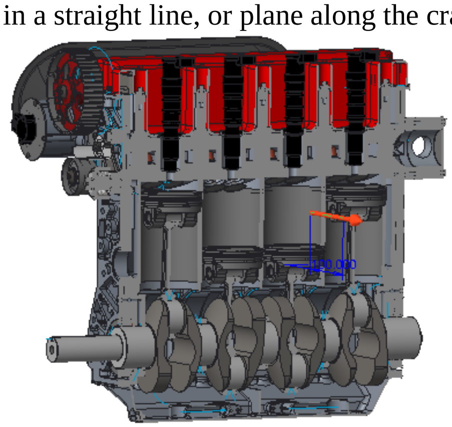

Fig.1 Inline Four Cylinder Engine

The inline-four layout is in perfect primary balance and confers a degree of mechanical simplicity which makes it popular for economy cars. However, despite its simplicity, it suffers from a secondary imbalance which causes minor vibrations in smaller engines. These vibrations become worse as engine size and power increase, so the more powerful engines used in larger

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cars generally are more complex designs with more than four cylinders. Today almost all manufacturers of four cylinder engines for automobiles produce the inline-four layout, with Subaru's flat-four being a notable exception, and so four cylinder is synonymous with and a more widely used term than inline-four. An even-firing inline-four engine is in primary balance because the pistons are moving in pairs, and one pair of pistons is always moving up at the same time as the other pair is moving down.

II. LITERATURE SURVEY

The common crankshaft material and manufacturing process technologies in use were compared with regards to their durability performance. This was followed by a discussion of durability assessment procedures used for crankshafts, as well as bench testing and experimental techniques. The variable intake and exhaust control valve system for the in-line four cylinder motorcycle engines was developed for realization of high engine power in all the engine speed ranges. The targets were set to realize the intake characteristics and the exhaust collecting pipes and engine performance by altering the way, the exhaust pipes were collected and connected to allow most efficient use of the exhaust pressure pulsation effects, and by adjusting the control valve. Shuhn Shyurng Hou et al (2004) studied the heat transfer effects and importance to provide good guidance for the performance evaluations and improvement of practical diesel engines. Compression ignition engine operates with a much higher compression ratio than spark ignition engines and, thus have higher efficiencies. These temperature loads will be varying from time to time in a cycle. These temperatures will be higher during firing stroke and lower during the other strokes. It is always difficult to assess the piston temperature for various gas temperatures. Analysis of the stress distribution in the various parts of the piston to know the stresses due to the gas pressure and thermal variations using with Ansys. With the definite-element analysis software, a three-dimensional definite-element analysis has been carried out to the gasoline engine piston.

III. METHODLOGY

An inline-four cylinder gasoline engine has to be designed to meet the stringent design requirements for automobiles. A comparative study of two different materials was conducted to choose the best suited materials. Grey cast iron (Fe40) was chosen for reference and the components will be analyzed. Using parameters, dimensions and features to capture the behavior of the product, it can optimize the development product as well as the design itself.

A. Material Selection

Grey cast iron (Fe40) is a type of the cast iron in which most or all of the carbon is uncombined in the form of the graphite flakes. It has graphite microstructure ad it has high thermal conductivity.

Table.1. Chemical Composition of Fe40

C	Si	S	P	Mn	Fe
2.8-3.30	1.20-1.70	$\leq$0.12	$\leq$0.15	0.702-1.20	93.53-95.03

Table.2. Physical Properties of Fe40

S.NO	PROPERTY	VALUE
1.	Density	7.2g/cm^3
2.	Melting Point	1180^{0}c
3.	Thermal Expansion	11/k
4.	Modulus of Elasticity	120Gpa
5.	Thermal Conductivity	46W/mk

B. Aluminium Alloy (Al6061):

Aluminium Alloy (Al6061) is one of the most widely used alloys in the 6000 Series. This standard alloy, is one of the most versatile of the heat-treatable alloys, and is popular for medium to high strength requirements. It has very good corrosion resistance and very good weld ability although reduced strength in the weld zone. It has medium fatigue strength.

Table.3. Chemical Composition of Al6061

Mg	Si	Fe	Cu	Cr	Zn	Ti	Mn	Al
0.8-1.2	0.4-0.8	0.0-0.7	0.15-0.40	0.04-0.35	0.0-0.25	0.0-0.15	0.0-0.15	96-98.61

C. Physical Properties:

Table.4. Physical Properties of Al6061

S.NO	PROPETRY	VALUE
1.	Density	$2.70g/cm^3$
2.	Melting Point	650^0c
3.	Thermal Expansion	$23.4\ x10^{-6}/k$
4.	Modulus of Elasticity	70Gpa
5.	Thermal Conductivity	166W/mk

D. DESIGN OF INLINE GASOLINE ENGINE

The Inline-four engine or Straight-four is an internal combustion engine with all four cylinders. All four cylinders are mounted in a straight line along one crankshaft. It can be powered by different types of fuels, including gasoline, diesel and natural gas. The single bank of cylinders may be in a vertical direction (straight up), or at an angle. When the cylinders are mounted at an angle. It is sometimes called a slant-four.

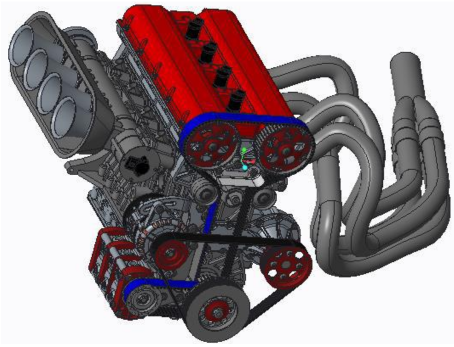

Fig.2 Model of Inline Gasoline Engine

The inline-four layout is a mechanically simple engine. It has a natural basic engine balance. It is smoother than one, two, and three cylinder engines. This makes it popular for economy cars. It does have a problem with secondary engine balance. This causes minor vibrations in smaller engines.

E. Cylinder Block:

The cylinder block is the largest part of the engine. Its upper section carries the cylinders and pistons. Normally, the lower section forms the crankcase, and supports the crankshaft. It can be cast in one piece from grey iron or it can be alloyed with other metals like nickel or chromium.

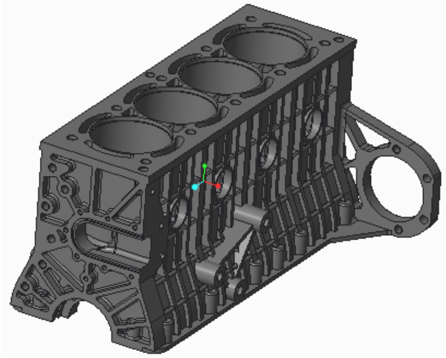

Fig.3 Model of Cylinder Block Forced convection

The iron casting process begins by making up the shapes of what will become water jackets and cylinders as sand **14** cores which are fitted into moulds. This stops these parts becoming solid iron during casting. Molten iron is poured into sand moulds that are formed by patterns in the shape of the block. After casting, core sand is removed through holes in the sides and ends, leaving spaces for the cooling and lubricant passages. These holes are sealed with core or welsh plugs. The casting is then machined. Cylinders are bored and finished, surfaces smoothed, holes drilled and threads cut.

F. Cylinder Head:

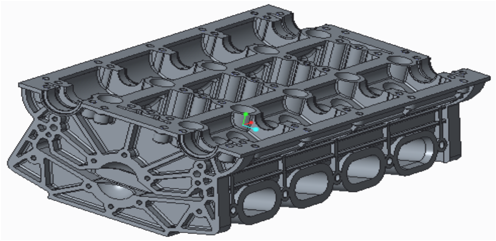

Fig.4 Model of Cylinder Head

Manufacturing the head is similar to manufacturing the block. A casting mold is made. Sand cores are put in to form any hollow areas. Depending on the engine, these can be for coolant and lubricant passages, and inlet and exhaust ports. Air-cooled engines have cooling fins cast into the cylinder head. The underside of the head is shaped to form the combustion chamber. Molten metal is poured in, and allowed to cool. The cores are broken out and removed, and the cylinder head cleaned of any sand. After casting comes machining. Surfaces that must seal are machined flat. Holes are drilled and tapped for attaching bolts and studs. In sand-cast heads, the large holes that had contained sand are machined, and then fitted with soft metal plugs, called core plugs.

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G. Piston:

The piston makes the crankshaft to turn by utilizing the energy supplied to it by the combustion of the fuel.

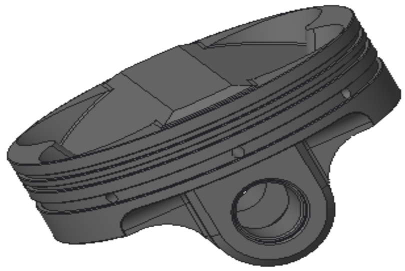

Fig.5 Model of Piston

The piston has four strokes in total, two upside and two down. During the intake stroke, the piston moves down and the cylinder is filled with air fuel mixture. The upward stroke compresses the mixture and as it reaches near the top position, the ignition of the fuel causes the piston to move downwards, the third stroke. During the fourth stroke, the piston moves upward and pushes the burnt gases to the exhaust system. The piston operates under high pressure and high temperature.

H. RINGS

A ring groove is a recessed area located around the perimeter of the piston that is used to retain a piston ring. Ring lands are the two parallel surfaces of the ring groove which function as the sealing surface for the piston ring. A piston ring **17** is an expandable split ring used to provide a seal between the piston and the cylinder wall.

Types of Rings:

- Compression/Pressure Rings
- Intermediate/Scraper Rings
- Oil Control Rings

I. Connecting Rod:

The connecting rod links the piston and the crankshaft. It has a hole at the upper end (small end) and is connected to the piston by the wrist pin. The lower end, also called as Big end, is attached to the crankshaft. The small end is press fit and can swivel in the piston. The Connecting rods are usually made of alloy steel, Titanium and sometimes with aluminum.

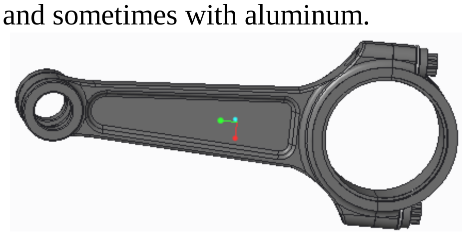

Fig.6 Connecting Rod

High factor of safety is provided as the failure of the connecting rod is very likely under such heavy stresses. Attention has to be paid to eliminate the stress risers in the connecting rod during production. Also, the bolts should be tightened with proper torque.

J. Crankshaft:

Crank Shaft, is the part of an engine which translates reciprocating linear piston motion into rotation. To convert the reciprocating motion into rotation, the crankshaft has "crank throws" or "crankpins", additional bearing surfaces whose axis is offset from that of the crank, to which the "big ends" of the connecting rods from each cylinder attach.

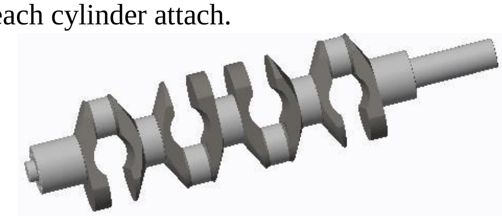

Fig.7 Model of Crankshaft

It typically connects to a flywheel, to reduce the pulsation characteristic of the four-stroke cycle, and sometimes a torsional or vibration damper at the opposite end, to reduce the torsion vibrations often caused along the length of the crankshaft by the cylinders farthest from the output end acting on the torsional elasticity of the metal.

K.Camshaft:

Camshaft is frequently called “brain” of the engine. This is so because its job is to open and closed at just the right time during engine rotation, so that the maximum power and efficient cleanout of exhaust to be obtained. The camshaft drives the distributor to electrically synchronize spark ignition. Camshafts do their work through eccentric "lobes" that actuate the components of the valve train.

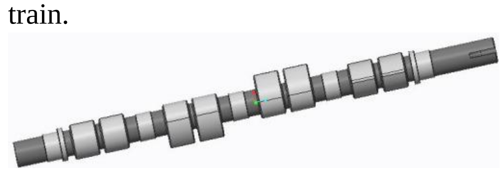

Fig.8 Model of Camshaft

The camshaft itself is forged from one piece of steel, on which the lobes are ground. On single-camshaft engines there are twice as many lobes as there are cylinders, plus a lobe for fuel pump actuation and a drive gear for the distributor. Driving the camshaft is the crankshaft, usually through a set of gears or a chain or belt. The camshaft always rotates at half of crank rpm,

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taking two full rotations of the crankshaft to complete one rotation of the cam, to complete a four- stroke cycle.

L. Valve:

The most commonly used valve is the poppet valve. The poppet valve has a straight cylinder rod and its end has the shape of a mushroom. The advantages of the poppet valve are that it is cheap, it has good flow properties, good seating, it is easy to lubricate, and it has good heat transfer to the cylinder head. Rotary and disc valves are sometimes used, but contrary to poppet valves, they have heat transfer, lubrication, and clearance problems.

Fig.9 Model of Valve

The other type of valve is the sleeve valve. The sleeve valve has some advantages over the poppet valve, but its disadvantages discontinued the use of it. The use of sleeve valves was best suited for aerospace engines before the introduction of the gas turbine engine. The advantages of sleeve valves were that they eliminated the hot spot associated with the poppet valve. Other advantages were that it produced higher outputs and higher efficiencies due to a higher compression ratio, which was due to the use of low octane fuel.

This mechanism is used when the need for two inlet and two exhaust valves are needed. High performance spark ignition engines or large compression ignition engines use the double overhead camshaft mechanism. One camshaft operates the inlet valves and the other camshaft operates the exhaust valves.

M. Exploded View Of Inline-Four Cylinder Gasoilne Engine

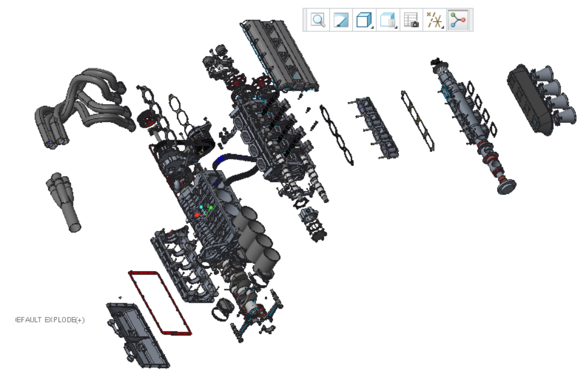

Fig.10 Exploded View of Inline Gasoline Engine

N. ENGINE SPECIFICATIONS

Table .5. Engine Specifications

1.	Engine type= Water cooled 4-stroke engine
2.	Fuel type = Petrol
3.	Bore x Stroke = 88mm x 80mm
4.	Displacement =1946cc(1.9lit)
5.	Maximum power = 105kw@6000rpm
6.	Maximum torque = 172Nm@2800rpm
7.	Compression ratio = 10:1
8.	Density of petrol = 737.22kg/m^3
9.	Temperature = 288.855k

O.Material Properties

Table .6. Material Properties

S.NO	Parameters	Fe40	Al6061
1.	Density (g/cm^3)	7.19	2.7
2.	Youngs modulus (GPa)	126	70-80
3.	Poisson's ratio	0.25	0.33

P. DESIGN CALCULATIONS

Density of petrol C8H18 = 737.22 kg/m3 at 60 ^{o}F
= 0.00073722 kg/cm3
= 0.00000073722 kg/mm3.
T = 600F =15.550C= 288.855K
Mass = density x volume
= 0.00073722 x 1946 = 1.43kg.
PV = mRT
P = (1.43 x 8.3143 x 288.555) / (0.11422 x 0.0001946)
= 154511495 J/m3
= 154.5 N/mm2.
Gas pressure, P =154.5N/mm2.

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Mean effective pressure, Pm = 1.202 N/m2.
Indicated power IP = (Pm x l x A x n)/60
= (1.202 x 80 x 3.14 x 88 x 4)/ (4 x 60)
= 136718.27 kw.
Brake power BP = (2 π N T) / 60
= (2 x 3.14 x 6000 x 172) / (4 x 60)
= 80937.05 kw.
Mechanical efficiency, = BP / IP
= 80937.05/136718.27
= 0.591
=59.1%

Q. Piston:

σt = allowable bending(tensile stress) for Al6061 = 50-90MPa

Piston Head thickness t1 = D x √ (3p/16σt) = 9.66mm.

Piston Ring Radial thickness t1 = D √ (3pw/σt) =1.93mm.

nr = no of rings = 3.

Axial thickness t2 = D/10nr = 1.9mm.

Width of the top land, b1=6.54mm.

Distance between ring grooves, b2 = t2 = 1.9mm.

Length of ring section = 5x (b2 or t2) = 9.5mm.

Total length of the piston, L = length of the skirt length of ring section + top land

L = 45.6 + 9.5 + 6.54 = 61.64mm.

R. Connecting Rod:

Length of connecting rod = 2times the stroke, L = 2x80= 160mm.

Thickness of flange and web of the section, t = 3.21mm.

Width of section, B=4t=12.84mm.

Height of section, H=5t=16.05=16mm.

Area, A=11t2=113.3mm.

S. Crankshaft:

D = piston diameter or cylinder bore = 88 mm.

P = maximum intensity of pressure on the piston = 154.5 N/mm2.

dc = Diameter of crankpin = 46mm.

lc = Length of crank pin = 22.5mm.

b = distance between the bearings 1 & 2 is equal to twice the piston diameter

= 2D = 2×88 = 176 mm.

T. Analysis Static Structural Analysis On Piston:

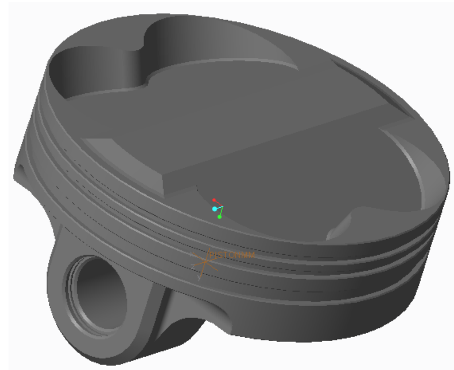

Fig.11 Cad Model of Piston

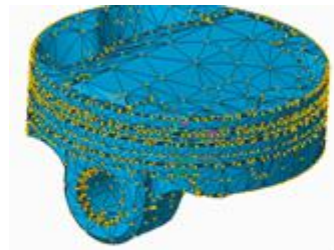

Fig.12 Meshed Model of Piston

U.Grey Cast Iron (Fe40):

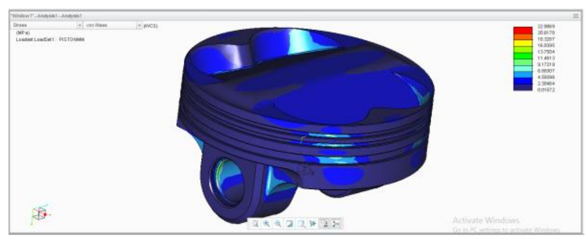

Fig.13 Stress Analysis

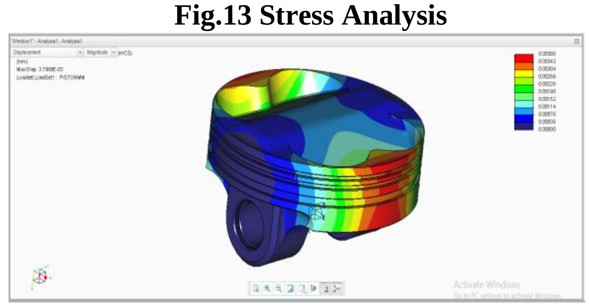

Fig.14 Total Deformation

V.Aluminium Alloy (Al6061):

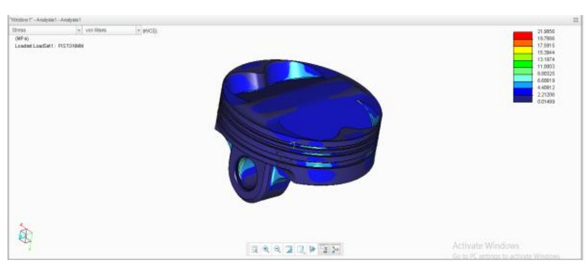

Fig.15 Stress Analysis

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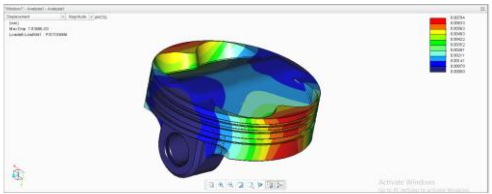


Fig.16 Total Deformation

Table .7 Static Analysis on Piston

S.NO	MATERIAL	VON MISES STRESS	TOTAL DEFORMATION
1.	Fe40	22.9069 MPa	0.00380 mm
2.	Al6061	21.9856 MPa	0.00704 mm

W. Static Structural Analysis on Connecting Rod:

Fig.17 Cad Model of Connecting Rod

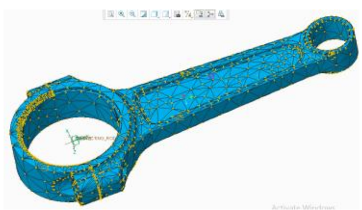


Fig.18 Meshed Model of Connecting Rod

X. Grey Cast Iron (Fe40):

Fig.19 Stress Analysis

Fig.20 Total Deformation

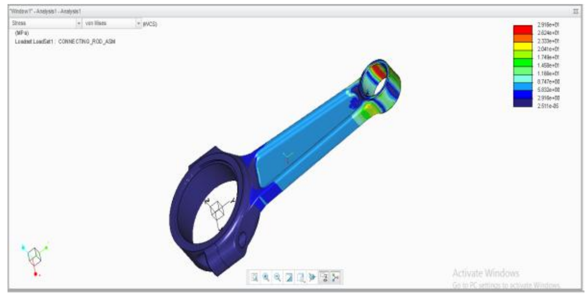


Fig.21 Stress Analysis

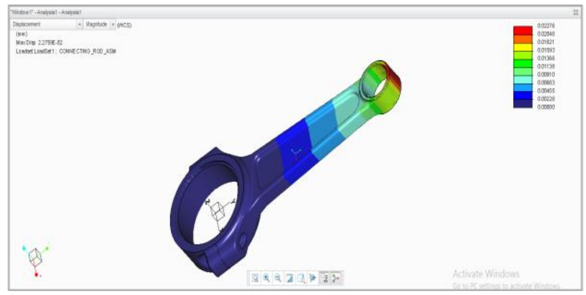


Fig.22 Total Deformation

IV. RESULT AND DISCUSSION

Table.8 Static Analysis on Connecting Rod

S.NO	MATERIAL	VON MISES STRESS	TOTAL DEFORMATION
1.	Fe40	2.976e+01 MPa	0.01239 mm
2.	Al6061	2.196e+01 MPa	0.02276 mm

A. Grey Cast Iron (Fe40):

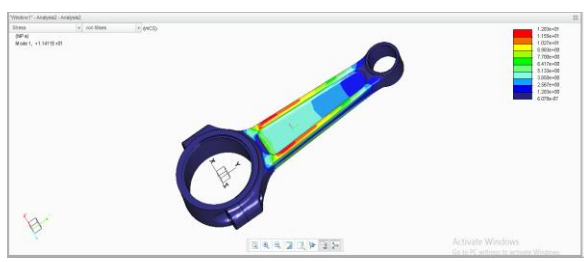


Fig.23 Stress Analysis

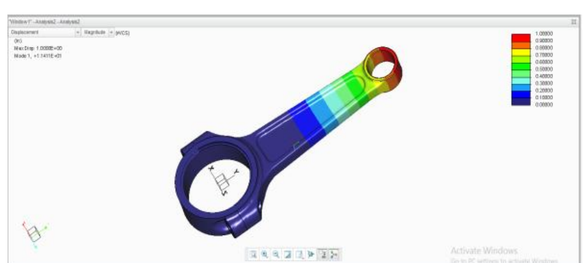
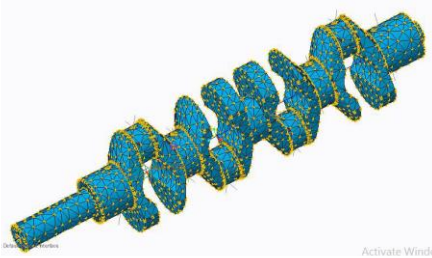


Fig.24 Total Deformation

Table.9. Buckling Analysis on Connecting Rod

S.NO	MATERIAL	VON MISES STRESS	TOTAL DEFORMATION
1.	Fe40	2.359e+01 MPa	25.4000 mm
2.	Al6061	1.283e+01 MPa	1.0000 mm

B. Static Structural Analysis on Crankshaft:



C. Grey Cast Iron (Fe40):

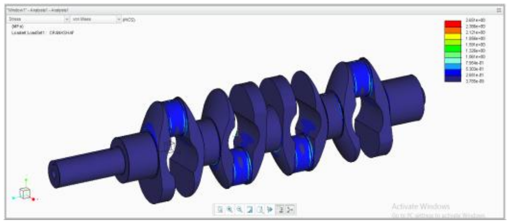


Fig.25 Stress Analysis

D. Aluminium Alloy (Al6061):

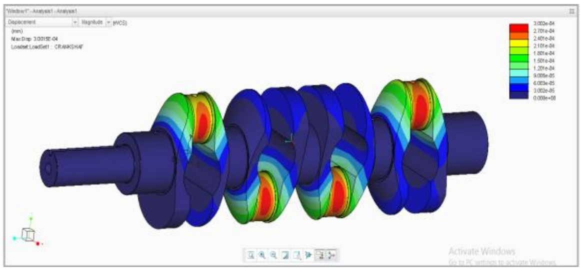


Fig.26 Stress Analysis and Deformation

Table.10. Overall Results

S.NO	COMPONENT	MATERIAL	VON MISES STRESS (MPa)	TOTAL DEFORMATION (mm)	MASS (kg)
1.	Piston (Static)	Fe40	22.9069	0.0038	8.8549e-1
		Al6061	21.9856	0.0070	3.3369e-1
2.	Connecting Rod (Static)	Fe40	29.7600	0.0123	3.2300e-1
		Al6061	21.9600	0.0227	1.2209e-1
3.	Connecting Rod (Buckling)	Fe40	23.5900	25.4000	3.2300e-1
		Al6061	12.8300	1.0000	1.2209e-1
4.	Crankshaft (Static)	Fe40	2.6510	1.615e-4	1.1385e+1
		Al6061	2.1290	3.002e-4	0.4290e+1

V. CONCLUSION

Internal Combustion engine is one of the most important inventions of the last Century. It has been developed in the late 1800s and from there on it has had a significant impact on our society. It has been and will remain for foreseeable future a vital role and active area of engineer research.

Using a CAD tool called CREO PARAMETRIC, Inline-four Cylinder Engine components are developed including few sub-assemblies they are Crank Shaft, Piston, Valves, and Cam Shaft. The main objective of this project is to know the designing process using CREO. This project is deals with the Modeling and analysis of these engine components. And analysis is done using CREO PARAMETRIC/ SIMULATION. Using this software, here we choose different type of materials for every component which are developed in DESIGN tool. The Analysis process is done in every manufacturing industry before assembling.

In present work, Grey cast iron (Fe40) and Aluminium Alloy (Al6061) are considered. The material which is chosen is better in weight. The results shows, the components with material Aluminium Alloy (Al6061) are better when compared to the components with material Grey cast iron (Fe40).

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