BUCKLING AND MODAL ANALYSIS OF CONNECTING ROD WITH DIFFERENT MATERIALS USING ANSYS

A project report submitted in partial fulfillment of the requirements for the Award of the Degree

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

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ABSTRACT

Connecting rod is one of the most important parts in automotive engine. The connecting rod is the intermediate member between the piston and the Crankshaft. Its primary function is to transmit the push and pull from the piston pin to the crank pin, thus converting the reciprocating motion of the piston into rotary motion of the crank.

In internal engines connecting rod is mainly made of steel and aluminium alloys (for light weight and absorb high impact loads) or titanium (for higher performance engines and for higher cost) or composite materials, composite materials is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. As a connecting rod is rigid, it may transmit either a push or a pull and so the rod may rotate the crank through both halves of a revolution, i.e. Piston pushing and piston pulling. Earlier mechanisms, such as chains, could only pull. In a few two-stroke engines, the connecting rod is only required to push. In which it undergoes structural deformations. Thus, in this project we are modelling a connecting rod using SOLIDWORKS modelling software and doing analysis in Ansys15 work bench software. Thus, the part which is modelled is converted into GES file to import in Ansys work bench and Buckling and Modal Analysis by applying various materials such as Aluminium Alloy, Magnesium Alloy, materials used in this project. By applying these boundary conditions on connecting rod the unknown variables such as stress, deformation, strain and factor of safety are found using the FEM Analysis based software (ANSYS15).

In this paper Finite element analysis of connecting rod used in single cylinder four stroke petrol engines is taken for the study. Buckling and Modal Analysis is conducted on connecting rod made up of different materials viz. Aluminium Alloy, Magnesium Alloy. Modelling and comparative analysis of connecting rod is carried out in commercially used FEM software ANSYS 15. 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.

1. INTRODUCTION

1.1 I.C ENGINES

As the name implies, the internal combustion engines (briefly written as I. C. engines) are those engines in which the combustion of fuel takes place inside the engine cylinder. The I.C. engines use either petrol or diesel as their fuel. In petrol engines (also called **engines spark ignition** or **S.I engines**), the correct proportion of air and petrol are mixed in the carburettor and fed to engine cylinder where it is ignited by means of a spark produced at the spark plug. In diesel engines (also called **compression ignition engines** or **C.I engines**), only air is supplied to the engine cylinder during suction stroke and it is compressed to a very high pressure, thereby raising its temperature from 600°C to 1000°C. The desired quantity of fuel (diesel) is now injected into the engine cylinder in the form of a very fine spray and gets ignited when comes in contact with the hot air.

The operating cycle of an I.C. engine may be completed either by the two strokes or four strokes of the piston. Thus, an engine which requires two strokes of the piston or one complete revolution of the crankshaft to complete the cycle is known as **two-stroke engine.** An engine which requires four strokes of the piston or two complete revolutions of the crankshaft to complete the cycle is known as **four-stroke engine.**

The two stroke petrol engines are generally employed in very light vehicles such as scooters, motor cycles and three wheelers. The two stroke diesel engines are generally employed in marine propulsion.

The four stroke petrol engines are generally employed in light vehicles such as cars, jeeps and also in aeroplanes. The four stroke diesel engines are generally employed in heavy duty vehicles such as buses, trucks, tractors, diesel locomotive and in the earth moving machinery.

1.2 Principal Parts of an Engine

The principal parts of an I.C engine, as shown in Fig.1 are as follows:

1. Cylinder and cylinder liner, 2. Piston, piston rings and piston pin or gudgeon pin, 3. Connecting rod with small and big end bearing, 4. Crank crankshaft and crank pin, and 5. Valve gear mechanism.

The design of the above-mentioned principal parts are discussed, in detail, in the following pages.

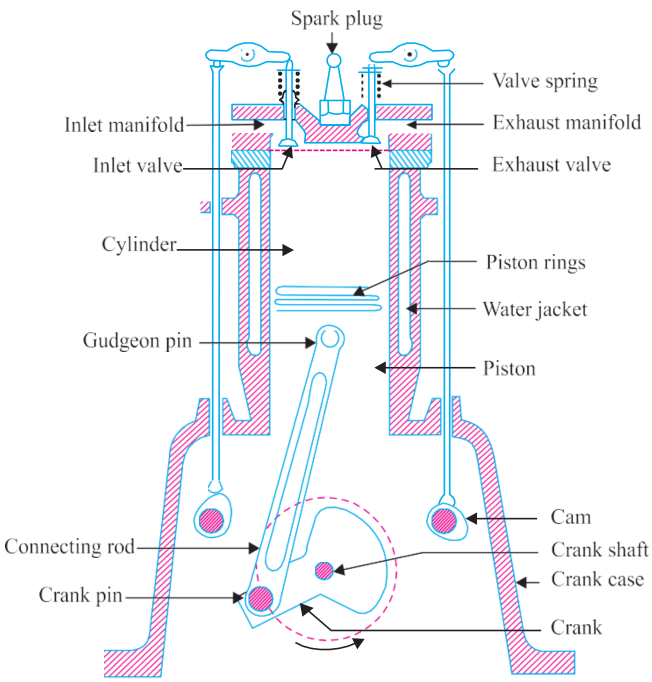


Fig.1 I.C Engine (S.I Engine)

1.3 Connecting Rod

The connecting rod is the intermediate member between the piston and the crankshaft. Its primary function is to transmit the push and pull from the piston pin to the crankpin and thus convert the reciprocating motion of the piston into the rotary motion of the crank. The usual form of the connecting rod in internal combustion engines is shown in Fig.1. It consists of a long shank, a small end and a big end. The cross-section of the shank may be rectangular, circular, tubular, *I*-section or *H*-section. Generally circular section is used for low-speed engines while *I*-section is preferred for high-speed engines.

The length of the connecting rod (l) depends upon the ratio of l / r, where r is the radius of crank. It may be noted that the smaller length will decrease the ratio l / r. This increases the angularity of the connecting rod which increases the side thrust of the piston against the cylinder liner which in turn increases the wear of the liner. The larger length of the connecting rod will increase the ratio l / r. This decreases the angularity of the connecting rod and thus decreases the side thrust and the resulting wear of the cylinder. But the larger length of the connecting rod increases the overall height of the engine. Hence, a compromise is made and the ratio l / r *is* generally kept as 4 to 5.

The small end of the connecting rod is usually made in the form of an eye and is provided with a bush of phosphor bronze. It is connected to the piston by means of a piston pin.

The big end of the connecting rod is usually made split (in two halves) so that it can be mounted easily on the crankpin bearing shells. The split cap is fastened to the big end with two cap bolts. The bearing shells of the big end are made of steel, brass or bronze with a thin lining (about 0.75 mm) of white metal or Babbitt metal.

The connecting rods are usually manufactured by drop forging process and it should have adequate strength, stiffness and minimum weight. The material mostly used for connecting rods varies from mild carbon steels (having 0.35 to 0.45 percent carbon) to alloy steels (chrome-nickel or chrome- molybdenum steels). The carbon steel having 0.35 percent carbon has an ultimate tensile strength of about 650 MPa when properly heat treated and carbon steel with 0.45 percent carbon has an ultimate tensile strength of 750 MPa. The alloy steels have an ultimate tensile strength of about 1050 MPa and are used for connecting rods of aero engines and automobile engines.

The bearings at the two ends of the connecting rod are either splash lubricated or pressure lubricated. The big end bearing is usually splash lubricated while the small end bearing is pressure lubricated. In the **splash lubrication system**, the cap at the big end is provided with a dipper or spout and set at an angle in such a way that when the connecting rod moves downward, the spout will dip into the lubricating oil contained in the sump. The oil is forced up the spout and then to the big end bearing. Now when the connecting rod moves upward, a splash of oil is produced by the spout. This splashed up lubricant find its way into the small end bearing through the widely chamfered holes provided on the upper surface of the small end. In the **pressure lubricating system,** the lubricating oil is fed under pressure to the big end bearing through the holes drilled in crankshaft, crank webs and crank pin. From the big end bearing, the oil is fed to small end bearing through a fine hole drilled in the shank of the connecting rod. In some cases, the small end bearing is lubricated by the oil scrapped from the walls of the cylinder liner by the oil scraper rings.

Fig.2 Two-Wheeler Connecting Rod

1.4 Types of Connecting Rod

Following are the types of connecting rod, used in various types of engines:

1. Plain type rod
2. Fork and blade rod
3. Master and slave rod
4. Billet conrods
5. Cast rods
6. Forged rods
7. Powered metal conrods

1.4.1 Plain Type Rods

The plain type of connecting rod is used in inline and opposed engines. The big end of the connecting rod is attached to the crankpin and fitted with a bearing cap.

The bearing cap is mounted by a bolt or stud at the end of the connecting rod. The connecting rod must be replaced in the same cylinder and in the same relative position to maintain proper fit and balance.

1.4.2 Fork and Blade Rods

These types of connecting rod are used on V-twin motorcycle engines and V12 aircraft engines. In each pair of engine cylinders, a “fork” rod is divided into two parts at the big end and a “blade” rod is tapered from the opposing cylinder to fit this gap in the fork.

This system eliminates the rocking couple that occurs when the cylinder pairs are balanced along with the crankshaft.

In the big-end bearings type of arrangement, the fork rod has a single wide-bearing sleeve that extends over the entire width of the rod, including the central gap.

The blade rod then runs directly outside this sleeve, not on the crankpin. This causes the two rods to move back and forth, this reducing the force on the bearing and the surface speed. But, the bearing speed also reciprocates instead of continuously rotating, which is a major problem for lubrication.

1.4.3 Master and Slave Rods

Radial engines typically use master-and-slave connecting rods. In this system, the one piston consists of a master rod with a direct attachment to the crankshaft. Other pistons connect their connecting rods to the rings surrounding the edge of the master rod.

The disadvantage of master-slave rods is that the stroke of the slave piston is slightly larger than that of the master piston, which increases the vibration in the V-type engine.

1.4.4 Billet rods

Billet connecting rods are designed from steel or aluminium. Compared to other types of connecting rod, they are lighter, stronger, and longer in lifespan.

It is commonly used in high-speed vehicles. It is sometimes designed to reduce stress risers and ease into the natural grain of the billet material.

Fig.3 Different types of Connecting Rods

1.4.5 Cast Rods

These types of connecting rod are preferred and designed by manufacturers because they can capable of handling the load of a stock engine.

Cast rods require low cost to produce and cannot be used in applications of high horsepower. The cast rods have a noticeable seam in the middle that separates them from the forged type.

1.4.6 Forged Rods

Some of the connecting rods are manufacture by forging. These types of connecting rod made by forcing a grain of material to the shape of the end. Depending on the required properties the material may be steel alloy or aluminium. Commonly used steel alloys are chrome and nickel alloy. The end product is not designed to be brittle. Hence, nickel or chrome alloys increase the strength of the connecting rod.

1.4.7 Powered Metal Connecting rods

Connecting rods are also designed from power metal as it is a suitable choice for manufacturers. It is prepared with a metal powder mixture that is pressed into the mould and heated to a high temperature. This mixture made into a solid form.

It may require light machining but the product basically comes out of a finished product mould. Conrods of powder metal are less costly than steel and they are stronger than cast rods.

Fig.4 Different Schafts in Connecting Rod

1.5 TYPES OF BEAMS

1.5.1 I-beam connecting rod:

I-beam connecting rods owe their name to their resemblance to a capital 'I' when you cut them apart. Connecting rods with an I-beam are the most common type of connecting rods and thus the ones most often used in serial production. They are cheap to manufacture and generally withstand more than they would actually need to in standard engines.

Standard I-beam connecting rods are often heavier than those with an H-beam. These are very lightweight and often sustain up to 1,000 hp, which is mainly due to the fact that they are milled out of solid, high-strength steel.

1.5.2 Connecting rod with H-beam:

The cross-section of connecting rods with an H-beam resembles a capital 'H', which is where they get their name from. They are designed for engines that run with a lot of hp at low speeds, usually charged engines with a turbocharger or compressor. These are optimal to withstand the pressure from compression. One example of this is our H-beam connecting rod for the 2.5L TFSI (Turbo fuel stratified injection) like in the Audi RS3.

1.5.3 X-beam, cross beam:

Connecting rods with an X-beam are the latest achievement from connecting rod manufacturers. They are like a sort of hybrid between I-beam and H-beam and combine the best properties of their predecessors. These connecting rods have a large cross-section, thereby distributing the tension across the entire connecting rod. Because of their high rigidity and crack resistance as well as minimal weight, they are basically made for racing.

1.6 Faults of Connecting Rods

A connecting rod is often subjected to large and repetitive forces during each rotation of the crankshaft. These created forces are proportional to the speed of the engine (RPM). While the connecting rod is continuously working in the crankshaft, it may damage or break. Following are the faults of a connecting rod:

1. Fatigue
2. Hydro lock
3. Over revving
4. Pin failure

1.6.1 Fatigue

Fatigue often occurs because the compression and stretch of the rod happen most of the time during the process. Eventually, this causes to wear of the rod till it gets breaks. Lack of oil and the presence of dirt in the engine can exacerbate this problem.

This is the most common type of defect and often occurs in older engines as well. If the engine is rebuilt, you may also experience fatigue in adding a new engine. Well, this happens when cheap parts or wrong parts are used.

1.6.2 Hydro lock

Hydro lock occurs when water enters the piston chamber causing deformation of the connecting rod. This may occur when vehicles pass through a flooded road. A little drop of water in the cylinder can produce knocking or tapping in the engine.

That can be easily corrected. But, if there is too much water in the cylinder, the spark is all over the place for a period of time, causing the cylinder rod to tilt or break.

1.6.3 Over Raving

Over raving is another type of fault of the connecting rod. That occurs in new and high-performance engines. If the tachometer displays a red colour, it indicates that the position of the connecting rod is in danger. This is because of forces working on the con rod rise dramatically at higher revolutions.

1.6.4 Pin Failure

Sometimes the piston pin is also damaged and results in catastrophic engine failure. This occurs when the connecting rod moves into the engine block or when the crankshaft is bent. In some engines, it can cause heavy power loss. The engine stops immediately when the pin breaks due to this problem. There is a possibility that the engine has survived, otherwise, a total breakdown may occur.

1.7 Forces Acting on the Connecting Rod

The various forces acting on the connecting rod are as follows:

1. Force on the piston due to gas pressure and inertia of the reciprocating parts,
2. Force due to inertia of the connecting rod or inertia bending forces,
3. Force due to friction of the piston rings and of the piston, and
4. Force due to friction of the piston pin bearing and the crankpin bearing.

We shall now derive the expressions for the forces acting on a vertical engine, as discussed below.

1.7.1 Force on the piston due to gas pressure & inertia of reciprocating parts

Consider a connecting rod *PC* as shown in Fig

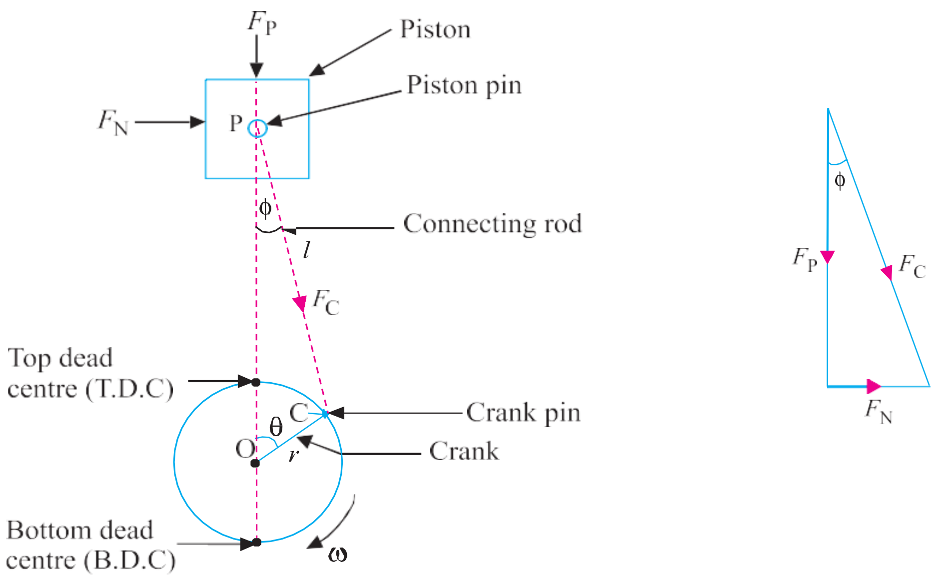


Fig.5 Forces on the connecting rod

Let p = Maximum pressure of gas,

D = Diameter of piston,

A = Cross-section area of piston = $\pi D^2/4$

m_R = Mass of reciprocating parts,

= Mass of piston, gudgeon pin etc + 1/3rd mass of Connecting rod,

ω = Angular speed of crank,

Φ = Angle of inclination of the connecting rod with the line of stroke,

Θ = Angle of inclination of the crank from top dead centre,

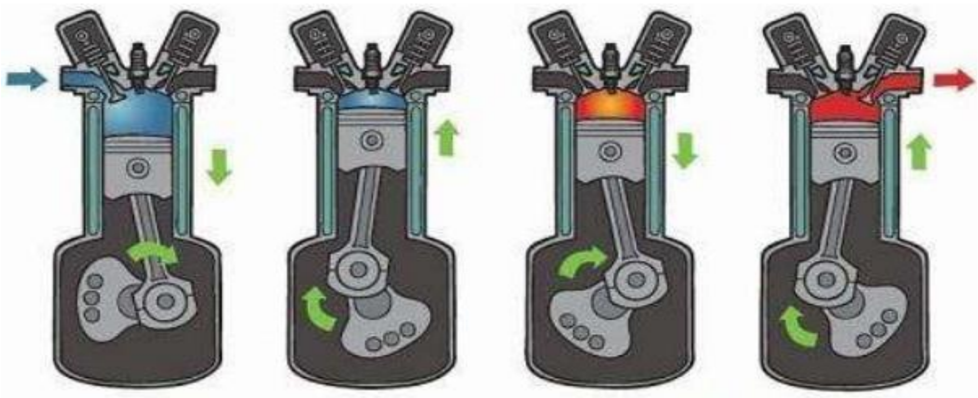


Fig.6 Different Phases in I.C Engine

r = Radius of crank,

l = Length of connecting rod, and

n = Ratio of length of connecting rod to radius of crank = l / r.

We know that the force on the piston due to pressure of gas,

F_L = Pressure × Area = p. A = $p \times \pi D^2 / 4$

and inertia force of reciprocating parts,

F_L = Mass × Acceleration = $m_R\, \omega^2 .\, r\, (\cos\theta + \frac{\cos 2\theta}{n})$

It may be noted that the inertia force of reciprocating parts opposes the force on the piston when it moves during its downward stroke (*i. e.* when the piston moves from the top dead centre to bottom dead centre). On the other hand, the inertia force of the reciprocating parts helps the force on the piston when it moves from the bottom dead centre to top dead centre.

∴ Net force acting on the piston or piston pin (or gudgeon pin or wrist pin),

F_P = Force due to gas pressure + Inertia force

$$F_p = F_L + F_I$$

The –ve sign is used when piston moves from TDC to BDC and +ve sign is used when piston moves from BDC to TDC.

When weight of the reciprocating parts ($W_R = m_R.\ g$) is to be taken into consideration, then

$$F_P = F_L + F_1 \pm W_R$$

The force F_P gives rise to a force F_C in the connecting rod and a thrust F_N on the sides of the cylinder walls. From Fig. 32.10, we see that force in the connecting rod at any instant,

$$F_C = F_P / \cos\Phi = \frac{F_P}{\sqrt{1 - \frac{\sin^2 \theta}{n^2}}}$$

The force in the connecting rod will be maximum when the crank and the connecting rod are perpendicular to each other (*i.e.* when q = 90°). But at this position, the gas pressure would be decreased considerably. **Thus, for all practical purposes, the force in the connecting rod (F_C) *is* taken equal to the maximum force on the piston due to pressure of gas (F_L)**, neglecting piston inertia effects.

1.7.2 Force due to inertia of the connecting rod or inertia bending forces

Consider a connecting rod PC and a crank OC rotating with uniform angular velocity w rad / s. In order to find the acceleration of various points on the connecting rod, draw the Klien's acceleration diagram CQNO as shown in Fig. 32.11 (a). CO represents the acceleration of C towards O and NO represents the acceleration of P towards O. The acceleration of other points such as D, E, F and G etc., on the connecting rod PC may be found by drawing horizontal lines from these points to intersect CN at d, e, f, and g respectively. Now dO, eO, fO and gO represents the acceleration of D, E, F and G all towards O. The inertia force acting on each point will be as follows:

Inertia force at C = $m \times w^2 \times CO$

Inertia force at D = $m \times w^2 \times dO$

Inertia force at E = $m \times w^2 \times eO$, and so on

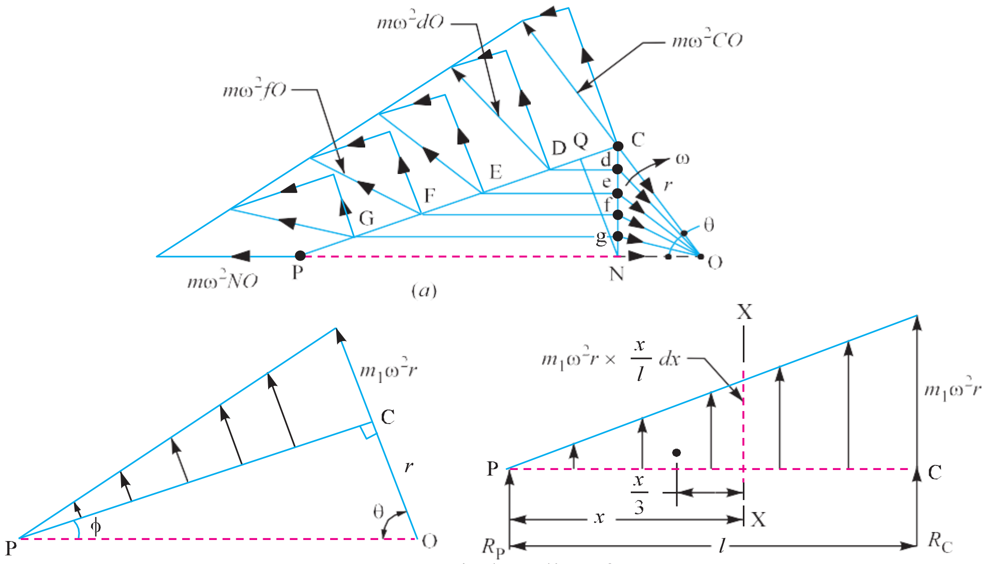


Fig.7 Inertia bending forces

The inertia forces will be opposite to the direction of acceleration or centrifugal forces. The inertia forces can be resolved into two components, one parallel to the connecting rod and the other perpendicular to rod. The parallel (or longitudinal) components adds up algebraically to the force acting on the connecting rod (F_C) and produces thrust on the pins. The perpendicular (or transverse) components produces bending action (also called whipping action) and the stress induced in the connecting rod is called ***whipping stress.***
It may be noted that the perpendicular components will be maximum, when the crank and connecting rod are at right angles to each other.

The variation of the inertia force on the connecting rod is linear and is like a simply supported beam of variable loading as shown in Fig. 32.11 (*b*) and (*c*). Assuming that the connecting rod is of uniform cross-section and has mass m_1 kg per unit length, therefore,
Inertia force per unit length at the crankpin = $m_1 \times w^2 r$
and inertia force per unit length at the piston pin = 0
Inertia force due to small element of length *dx* at a distance *x* from the piston pin *P*,

$$dF = m \times w^2 r \times {}^{x} \times dx$$

Resultant inertia force, acting on the connecting rod (F_C) and produces thrust on the pins. The perpendicular (or transverse) components produces bending action (also called whipping action) and the stress induced in the connecting rod is called ***whipping stress.***

It may be noted that the perpendicular components will be maximum, when the crank and connecting rod are at right angles to each other. The variation of the inertia force on the connecting rod is linear and is like a simply supported beam of variable loading as shown in Fig. 7. Assuming that the connecting rod is of uniform cross-section and has mass m_1 kg per unit length, therefore,

Inertia force per unit length at the crankpin = $m_1 \times w^2 r$

and inertia force per unit length at the piston pin = 0.

Inertia force due to small element of length '*dx*' at a distance *x* from the piston pin *P*,

$$dF_1 = m_1 \times \omega^2 r \times \frac{x}{l} \times dx$$

. Resultant inertia force,

$$F_I = \int_0^l m_1 \times \omega^2 r \times \frac{x}{l} \times dx = \frac{m_1 \times \omega^2 r}{l}\left[\frac{x^2}{2}\right]_0^l$$

$$= \frac{m_1 . l}{2} \times \omega^2 r = \frac{m}{2} \times \omega^2 r \qquad \text{...(Substituting } m_1 \cdot l = m)$$

This resultant inertia force acts at a distance of 2l / 3 from the piston pin P.

Since it has b assumed that 1/3rd mass of the connecting rod is concentrated at piston pin *P*

(*i.e.* small end of connecting rod) and 2/3rd at the crankpin (*i.e.* big end of connecting rod), therefore**,** the reaction at these two ends will be in the same proportion. i.e.

$$R_P = \frac{1}{3} F_I, \text{ and } R_C = \frac{2}{3} F_I$$

Now the bending moment acting on the rod at section $X - X$ at a distance x from P,

$$M_X = R_P \times x - {}^*m_1 \times \omega^2 r \times \frac{x}{l} \times \frac{1}{2} x \times \frac{x}{3}$$

$$= \frac{1}{3} F_I \times x - \frac{m_1 . l}{2} \times \omega^2 r \times \frac{x^3}{3l^2}$$

...(Multiplying and dividing the latter expression by l)

$$= \frac{F_I \times x}{3} - F_I \times \frac{x^3}{3l^2} = \frac{F_I}{3}\left(x - \frac{x^3}{l^2}\right) \qquad \text{...}(\mathbf{\textit{i}})$$

For maximum bending moment, differentiate M_X with respect to x and equate to zero, *i.e.*

$$\frac{d_{MX}}{dx} = 0 \quad \text{or} \quad \frac{F_I}{3}\left[1 - \frac{3x^2}{l^2}\right] = 0$$

$$\therefore \quad 1 - \frac{3x^2}{l^2} = 0 \quad \text{or} \quad 3x^2 = l^2 \quad \text{or} \quad x = \frac{l}{\sqrt{3}}$$

Maximum bending moment,

$$M_{max} = \frac{F_I}{3}\left[\frac{l}{\sqrt{3}} - \frac{\left(\frac{l}{\sqrt{3}}\right)^3}{l^2}\right] \qquad \text{...[From equation } (i)]$$

$$= \frac{F_I}{3}\left[\frac{l}{\sqrt{3}} - \frac{l}{3\sqrt{3}}\right] = \frac{F_I \times l}{3\sqrt{3}} \times \frac{2}{3} = \frac{2F_I \times l}{9\sqrt{3}}$$

$$= 2 \times \frac{m}{2} \times \omega^2 r \times \frac{l}{9\sqrt{3}} = m \times \omega^2 r \times \frac{l}{9\sqrt{3}}$$

and the maximum bending stress, due to inertia of the connecting rod,

$$\sigma_{max} = \frac{M_{max}}{Z}$$

where Z = Section modulus.

From above we see that the maximum bending moment varies as the square of speed, therefore, the bending stress due to high speed will be dangerous. It may be noted that the maximum axial force and the maximum bending stress do not occur simultaneously. In an I.C. engine, the maximum gas load occurs close to top dead centre whereas the maximum bending stress occurs when the crank angle q = 65° to 70° from top dead centre. The pressure of gas falls suddenly as the piston moves from dead centre. Thus the general practice is to design a connecting rod by assuming the force in the connecting rod (F_C) equal to the maximum force due to pressure (F_L), neglecting piston inertia effects and then checked for bending stress due to inertia force (i.e. whipping stress).

1.7.3 Force due to friction of piston rings and of the piston

The frictional force (F) of the piston rings may be determined by using the following expression

$$F = \text{p}\, D \cdot t_R \cdot n_R \cdot p_R \cdot \text{m}$$

Where, D = Cylinder bore,

t_R = Axial width of rings,

n_R = Number of rings,

p_R = Pressure of rings (0.025 to 0.04 N/mm^2), and

μ = Coefficient of friction (about 0.1).

Since the frictional force of the piston rings is usually very small, therefore, it may be neglected. The friction of the piston is produced by the normal component of the piston pressure which varies from 3 to 10 percent of the piston pressure. If the coefficient of friction is about 0.05 to 0.06, then the frictional force due to piston will be about 0.5 to 0.6 of the piston pressure, which is very low. Thus, the frictional force due to piston is also neglected.

1.7.4 Force due to friction of the piston pin bearing and crankpin bearing

The force due to friction of the piston pin bearing and crankpin bearing is to bend the connecting rod and to increase the compressive stress on the connecting rod due to the direct load. Thus, the maximum compressive stress in the connecting rod will be

$\sigma_{c\,(max)}$ = Direct compressive stress + Maximum bending or whipping stress due to Inertia bending stress

1.8 DESIGN FOR PRESSURE CALCULATION

Consider 150cc Engine

Specifications

Engine type	=	air cooled 4-stroke
Bore x Stroke (mm)	=	57 x 58.6
Displacement	=	149.5 CC
Maximum Power	=	13.8 bhp @ 8500 rpm
Maximum Torque	=	13.4 Nm @ 6000 rpm
Compression Ratio	=	9.35:1
Density of Petrol ($C8H18$)	=	737.22 kg/m^3
	=	737.22x10^9 kg/mm^3
Auto ignition temp.	=	288.85°K
Mass	=	Density x Volume
	=	737.22x10^{9}x149.5x10^3
	=	0.110214 kg
Molecular weight of petrol	=	114.228 g/mole
	=	0.11423 kg/mole

from gas equation,

PV = m x R x T

Where,

P	=	Gas Pressure, Mpa
V	=	Volume
m	=	mass, kg
T	=	Temperature, °k
R	=	Specific gas constant = R/M
	=	8.3144/0.114225
	=	72.788 Nm/kg K
P	=	m x R x T/V
	=	0.110214 x 72.788 x (288.85/149.5)
	=	15.49 Mpa ≈ **16 Mpa**

∴Calculation is done for max pressure of 16 Mpa.

1.8.1 Calculating Load Acting on Connecting Rod by Gases

F_1 = (π/4) x (bore) ^{2} x Gas Pressure (P)

F_1 = 39.552 x 10^3 N

1.8.2 Calculation for Buckling Load

W_B = Load acting of connecting rod (F) x F.O.S

W_B = 37663 N

I_{xx} = 34.91 t_4

$I_{yy} = 10.91\ t_4$
Area of section (A) = $11\ t^2$
Height of Section (H) = 5t
Width of Section (B) = 4t

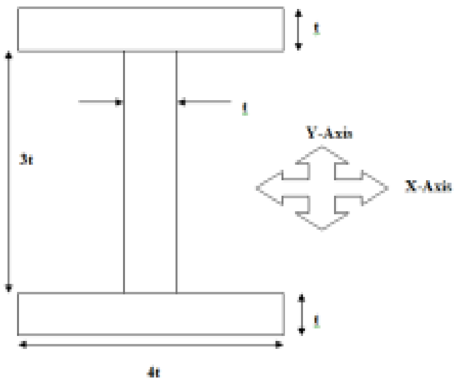


Fig.8 I-Section

Therefore, by using Rankine's Formula
$W_B = (\sigma_c \times A)/(1 + \alpha(L/K_{XX})^2)$
By solving the Rankine's Formula,
we get the value of 't' as 3.2 mm

1.8.2.1 Design of Small End

$F_g = d_1$ (inner dia.) x $L_1 \times P_{bp}$ (d_1 = 17.94 mm)
$L_1 = 1.5 \times d_1$ = 26.94 mm
Outer Diameter (d_2) = $d_1 + 2t_b + 2t_m$ = 31.94 mm

1.8.2.2 Design of Big End

$F_g = D_3$ (inner dia.) x $L_2 \times P_{bp}$

- D_3 = 23.88 mm
- $L_1 = 1 \times D_3$

Outer Diameter (d_4) = $D_3 + 2t_b + 2t_m + 2b_d$
= 47.72 mm

Connecting Rod Dimensions:

S. No.	Parameters (mm)
1.	Thickness of the connecting rod (t) = 3.2
2.	Width of the section (B = 4t) = 12.8
3.	Height of the section(H = 5t) = 16
4.	Height at the big end = (1.1 to 1.125)H = 17.6
5.	Height at the small end = 0.9H to 0.75H = 14.4
6.	Inner diameter of the small end = 17.94
7.	Outer diameter of the small end = 31.94
8.	Inner diameter of the big end = 23.88
9.	Outer diameter of the big end = 47.72

Table:-1

1.9 PROBLEM STATEMENT

The objective of the present work is to develop solid model of connecting rod of single cylinder-four stroke S.I engine using SOLIDWORKS V15.0 software. Modal and Buckling Analysis are performed using FEA software ANSYS 15.0. The materials used in this study are Aluminium Alloys AL 2024-T3, AA 6061-T6, AA 7075-T6 and Magnesium Alloy .Output parameters of Modal and Buckling Analysis are von Mises stress, total deformation.

1.10 PROBLEM OBJECTIVES

1. To design the connecting rod for a petrol engine so as to determine the section thickness of connecting rod.
2. To geometrically model the connecting rod as per the dimensions generated from the process of design procedure followed.
3. To analyse the buckling load which is equivalent stress due to inertia forces acting on each material of connecting rod.
4. To analyse the stresses using FEA approach on each material selected for study.

2 LITERATURE REVIEW

B. Anusha et al [1] presented work on "Comparison of materials for Two wheeler Connecting Rod using ANSYS. The modelled connecting rod imported to ANSYS software for analysis. Analysis is done to determine von misses stresses, shear stresses and strain. In this study two materials are selected and analysed. The result is helpful and utilize in designing the connecting rod.

Singh [2] had conducted a study in which the conventional material of connecting rod i.e. steel or cast iron is replaced with composite material (E-Glass/Epoxy). By using FEA method von misses stresses, distortion and other effective parameters are ascertained. There was reduction of 33.9% of stresses when comparing with present material replaced with (E-Glass/Epoxy).

Ramakrishna and Venkat [4] had carried out a study of connecting rod of petrol engine of LML freedom. The work focused on optimization of the material in which current 4340 alloy steel connecting rods are replaced by AlSiC 9 results in a 61.65 % reduction in weight.

A. Prem Kumar [5] had carried out a study in which the present material Al 6061 is replaced by Al 6061 + B4C. When compared with present material, Al 6061 + B4C have lowerdeformation and also sustain a low Von misses strain. Thus result in high hardness.

Bin Zheng, Yongqi Lou and Ruixiang Liu [6] had carried out a study in which the material utilized for connecting rod in small commercial vehicle is 40Cr. It was analysis that maximum compression condition increases and factor of safety of connecting rod increases by 59%.

K. Sudershan Kumar et al. [7] "Modelling and Analysis of Two Wheeler Connecting Rod," In this paper connecting rod material is replaced by Aluminium coated with Boron carbide. A model is design by using PRO-E software and analysis is done on ANSYS software.

G. Naga MalleshwaraRao et al. [8] “Design Optimization and Analysis of a Connecting Rod using ANSYS” The aim of this work is to find opportunities for weight reduction by analyzing various material like Genetic Steel, Aluminium, Titanium and Cast Iron.

Prof. Vivek C. Pathade (2013) [9] worked on the stress analysis of connecting rod by Finite Element Method using Pro/E Wildfire 4.0 and Ansys Workbench 11.0 software. Experimental method of Photoelastic is used for comparison and verification of the results obtained in FEA.From the FEA and Photoelastic Analysis he found that the stresses induced in the small end of the connecting rod are higher than the stresses induced at the big end. It is also found from the photoelastic that the stress concentration effect exist at both small end and big end and it is negligible in the middle portion of the connecting rod. Therefore, the connecting rod fails may be at fillet section of both ends.

G. M. Sayeed Ahmed [10] worked on “Design Fabrication and Analysis of a Connecting Rod with Aluminium Alloys and Carbon Fibre” he replaced a forged steel connecting rod with Aluminium alloy and Carbon fibre. The Connecting Rod is modelled on Pro/E. Connecting rod of materials aluminium6061, aluminium 7075, aluminium 2014 and carbon fibre 280 GSM are used and analysis is done.

Bagri & Telang [11] focus his work on optimization of shank fillet radius to reduce maximum equivalent von misses stress. In optimization it is found that shank fillet radius has big influence on the stress distribution on the shank portion of the connecting rod. Modal analysis is done with changed shank fillet radius and reduced deformation was observed in the model and compared with the initial model.

CHAPTER-3

MATERIALS AND THEIR PROPERTIES

3 MATERIALS AND THEIR PROPERTIES

From the literature survey we did, we were able to finalize the materials we think would be suitable for the task. We have decided to use three different materials all of which belong to the alloy family. The reason for choosing alloy is due to the many advantages they possess compared to metals.

3.1 CONNECTING ROD MATERIALS

Commonly used as steel alloy, aluminum and titanium steel alloys like 42CrMo4, 43CrMo4,44csr4, C-70,EN-8D, SAE1141, etc. It is steel that is alloyed with a variety of elements in total amounts between 1.0% and 50% by weight to improve its mechanical properties. Alloy steels are broken down arbitrarily Smith and Hashemi define the difference at 4.0%, while Degarmo, and define it at 8.0% .Most commonly, the phrase "alloy steel" refers to low-alloy steels. Strictly speaking, every steel is an alloy, but not all steels are called "alloy steels". The simplest steels are iron (Fe) alloyed with carbon(C) (about 0.1% to 1%, depending on type). However, the term "alloy steel" is the standard term referring to steels with other alloying elements added deliberately in addition to the carbon. Common alloyants include manganese (the most common one), nickel, chromium, molybdenum, vanadium, silicon, and boron. Less common alloyants include aluminum, cobalt, copper, cerium, niobium, titanium, tungsten, tin, zinc, lead, and zirconium. Aluminum alloys like T6-2024 and T651-7075 also light and has the ability to absorb high impact. It is alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al–Si, where the high levels of silicon (4.0–13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Titanium is used in high performance engines. It is light and strong, but comes at a higher cost. It is a chemical element with symbol Ti and atomic number 22. It is a lustrous transition metal with a silver colour, low density, and high strength. Titanium is resistant to corrosion in sea water, aqua regia, and chlorine. Cast Iron can be used for smaller applications like two wheelers. Cast iron is a group of iron carbon alloys with a carbon content greater than 2% Its usefulness derives from its relatively low melting temperature. The alloy constituents affect its colour when fractured: white cast iron has carbide impurities which allow cracks to pass straight through, grey cast iron has graphite flakes which deflect a passing crack and initiate countless new cracks as the material breaks, and ductile cast iron has spherical graphite "nodules" which stop the crack from further progressing. Carbon (C) ranging from 1.8–4 wt%, and silicon (Si) 1–3 wt% are the main alloying elements of cast iron. Iron alloys with lower carbon content (~0.8%) are known as steel. While this technically makes the Fe–C–Si system ternary, the principle of cast iron solidification can be understood from the simpler binary iron–carbon phase diagram. Since the compositions of most cast irons are around the eutectic point (lowest liquid point) of the iron–carbon system, the melting temperatures usually range from 1,150 to 1,200 °C (2,100 to 2,190 °F), which is about 300°C (540 °F) lower than the melting point of pure iron of 1,535 °C (2,795 °F).

• Galling, the process whereby cold-welding of material causes seizure, does not affect steel.
• Steel is no need to worry when inserting a bush, or when re-bushing con rods.
• The stiffness of steel is much higher than that of titanium.
• Its density of 7.85 g/cc, it is almost 80% more dense than a typical titanium.

The following are the Material Alloys finalized for Analysis

1. Aluminium Alloy
2. Magnesium Alloy

There are many reasons for choosing these two materials for the analysis part. Aluminium Alloy happens to be the most widely used material in the manufacturing of connecting rod while due to low fatigue life, when used under high stress situations drag racing only. It can be used safely with daily driving. Aluminium rods are the best choice for DSM's, strong and light. Magnesium Alloy is used in making the different parts in automotive industry but the cases of implementing it for connecting rod seems rare. Of the three materials Magnesium Alloy happens to be the cheapest material available in our country at present. The analysis we'll perform will help us in understanding the reason for why certain materials is preferred over the other for the making of a connecting rod. That is one of the reasons for choosing these materials.

3.2 Aluminium alloys

An **Aluminium alloy** is an alloy in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al–Si, where the high levels of silicon (4.0–13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required.

Aluminium alloy compositions are registered with The Aluminium Association. Many organizations publish more specific standards for the manufacture of aluminium alloy, including the Society of Automotive Engineers standards organization, specifically its aerospace standards subgroups, and ASTM International.

3.2.1 Engineering use and aluminium alloys properties

Aluminium alloys with a wide range of properties are used in engineering structures. Alloy systems are classified by a number system (ANSI) or by names indicating their main alloying constituents (DIN and ISO). Selecting the right alloy for a given application entails considerations of its tensile strength, density, ductility, formability, workability, weldability, and corrosion resistance, to name a few. Aluminium alloys are used extensively in aircraft due to their high strength-to-weight ratio. On the other hand, pure aluminium metal is much too soft for such uses, and it does not have the high tensile strength that is needed for airplanes and helicopters.

3.2.2 Aluminium alloys versus types of steel

Aluminium alloys typically have an elastic modulus of about 70 GPa, which is about one-third of the elastic modulus of steel alloys. Therefore, for a given load, a component or unit made of an aluminium alloy will experience a greater deformation in the elastic regime than a steel part of identical size and shape. With completely new metal products, the design choices are often governed by the choice of manufacturing technology. Extrusions are particularly important in this regard, owing to the ease with which aluminium alloys, particularly the Al–Mg–Si series, can be extruded to form complex profiles.

In general, stiffer and lighter designs can be achieved with Aluminium alloy than is feasible with steels. For instance, consider the bending of a thin-walled tube: the second moment of area is inversely related to the stress in the tube wall, i.e. stresses are lower for larger values. The second moment of area is proportional to the cube of the radius times the wall thickness, thus increasing the radius (and weight) by 26% will lead to a halving of the wall stress. For this reason, bicycle frames made of aluminium alloys make use of larger tube diameters than steel or titanium in order to yield the desired stiffness and strength. In automotive engineering, cars made of aluminium alloys employ space frames made of extruded profiles to ensure rigidity. This represents a radical change from the common approach for current steel car design, which depend on the body shells for stiffness, known as unibody design.

Aluminium alloys are widely used in automotive engines, particularly in cylinder blocks and crankcases due to the weight savings that are possible. Since aluminium alloys are susceptible to warping at elevated temperatures, the cooling system of such engines is critical. Manufacturing techniques and metallurgical advancements have also been instrumental for the successful application in automotive engines. In the 1960s, the aluminium cylinder heads of the Corvair earned a reputation for failure and stripping of threads, which is not seen in current aluminium cylinder heads. An important structural limitation of aluminium alloys is their lower fatigue strength compared to steel. In controlled laboratory conditions, steels display a fatigue limit, which is the stress amplitude below which no failures occur – the metal does not continue to weaken with extended stress cycles. Aluminium alloys do not have this lower fatigue limit and will continue to weaken with continued stress cycles. Aluminium alloys are therefore sparsely used in parts that require high fatigue strength in the high cycle regime (more than 107 stress cycles).

3.2.3 Alloy designations

Wrought and cast aluminium alloys use different identification systems. Wrought aluminium is identified with a four digit number which identifies the alloying elements.

Cast aluminium alloys use a four to five digit number with a decimal point. The digit in the hundreds place indicates the alloying elements, while the digit after the decimal point indicates the form (cast shape or ingot).

3.2.4 Temper designation

The temper designation follows the cast or wrought designation number with a dash, a letter, and potentially a one to three digit number, e.g. 6061-T6. The definitions for the tempers are

-F : As fabricated

-H : Strain hardened (cold worked) with or without thermal treatment

> **-H1** : Strain hardened without thermal treatment
>
> **-H2** : Strain hardened and partially annealed
>
> **-H3** : Strain hardened and stabilized by low temperature heating
>
> **Second digit** : A second digit denotes the degree of hardness
>
> -HX2 = 1/4 hard
>
> -HX4 = 1/2 hard
>
> -HX6 = 3/4 hard
>
> -HX8 = full hard
>
> -HX9 = extra hard

-O : Full soft (annealed)

-T : Heat treated to produce stable tempers

> **-T1** : Cooled from hot working and naturally aged (at room temperature)
>
> **-T2** : Cooled from hot working, cold-worked, and naturally aged
>
> **-T3** : Solution heat treated and cold worked
>
> **-T4** : Solution heat treated and naturally aged
>
> **-T5** : Cooled from hot working and artificially aged (at elevated temperature)

-T51 : Stress relieved by stretching

-T510 : No further straightening after stretching

-T511 : Minor straightening after stretching

-T52 : Stress relieved by thermal treatment

-T6 : Solution heat treated and artificially aged

-T7 : Solution heat treated and stabilized

-T8 : Solution heat treated, cold worked, and artificially aged

-T9 : Solution heat treated, artificially aged, and cold worked

-T10 : Cooled from hot working, cold-worked, and artificially aged

-W : Solution heat treated only

Note: -W is a relatively soft intermediary designation that applies after heat treat and before aging is completed. The -W condition can be extended at extremely low temperatures but not indefinitely and depending on the material will typically last no longer than 15 minutes at ambient temperatures.

3.2.5 Wrought alloys

The International Alloy Designation System is the most widely accepted naming scheme for wrought alloys. Each alloy is given a four-digit number, where the first digit indicates the major alloying elements, the second — if different from 0 — indicates a variation of the alloy, and the third and fourth digits identify the specific alloy in the series. For example, in alloy 3105, the number 3 indicates the alloy is in the manganese series, 1 indicates the first modification of alloy 3005, and finally 05 identifies it in the 3000 series

- 1000 series are essentially pure aluminium with a minimum 99% aluminium content by weight and can be work hardened.
- 2000 series are alloyed with copper, can be precipitation hardened to strengths comparable to steel. Formerly referred to as duralumin, they were once the most common aerospace alloys, but were susceptible to stress corrosion cracking and are increasingly replaced by 7000 series in new designs.
- 3000 series are alloyed with manganese, and can be work hardened.

- 4000 series are alloyed with silicon. Variations of aluminium-silicon alloys intended for casting (and therefore not included in 4000 series) are also known as silumin.
- 5000 series are alloyed with magnesium, and offer superb corrosion resistance, making them suitable for marine applications. Also, 5083 alloy has the highest strength of not heat-treated alloys. Most 5000 series alloys include manganese as well.
- 6000 series are alloyed with magnesium and silicon. They are easy to machine, are weldable, and can be precipitation hardened, but not to the high strengths that 2000 and 7000 can reach. 6061 alloy is one of the most commonly used general-purpose aluminium alloys.
- 7000 series are alloyed with zinc, and can be precipitation hardened to the highest strengths of any aluminium alloy (ultimate tensile strength up to 700 MPa for the 7068 alloy). Most 7000 series alloys include magnesium and copper as well.
- 8000 series are alloyed with other elements which are not covered by other series. Aluminium-lithium alloys are an example.

3.3 AL 2024

The matrix material utilized in the current study is Al2024. The distinctive alloying parts are magnesium, copper, manganese, element, and atomic number 30. It belongs to a gaggle of hypo mixture Al-Si-B alloys and includes a wide field of application within the automotive and aeronautics industries. Besides this, the Al 2024 alloy is employed as a matrix for getting composites that have Associate in Nursing increased wear resistance, favourable mechanical properties at temperature, and increased mechanical properties at elevated temperatures. Al 2024 alloys naturally have Associate in nursing modulus of elasticity of regarding 73.1 GPa. In general, stiffer and lighter styles are achieved with Al 2024 alloys than is feasible with steels. 2024 is commonly extruded, and also available in alclad sheet and plate forms. It is not commonly forged.

3.3.1 AL 2024-T3

T3 is an alloy of the same composition that has been furnace solution heat treated, quenched to room temperature, and cold worked.

Table:-2

Base Material	**Al 2024**
Density value	2.78 g/cm^3
Young's modulus value	73.1Gpa
Tensile strength value	140-210Mpa
Elongation at break value	19-27%
Poisson's ratio value	0.33
Melting temperature value	500°c
Thermal conductivity value	151-202 W/(m-k)
Linear thermal expansion coefficient value	2.34X10^{-5}
Specific heat capacity value	897 J/(kg-k)

3.3.2 Applications of Al2024:

2024 aluminium has excellent machinability, good workability, high strength, and can be made to resist corrosion with cladding, making it an optimal choice for aircraft and vehicle applications. 2024 aluminium is used throughout many industries, but some common applications for this excellent alloy are as follows:

- Rail coaches
- Military and commercial bridges
- Ship building operations
- Towers and pylons
- Rivets
- Aerospace applications (i.e., helicopter rotor skins)
- Transport operations.

3.4 6061 Aluminium Alloy

6061 (Unified Numbering System (UNS) designation A96061) is a precipitation-hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. Originally called "Alloy 61S", it was developed in 1935. It has good mechanical properties, exhibits good weldability, and is very commonly extruded (second in popularity only to 6063). It is one of the most common alloys of aluminium for general-purpose use.

It is commonly available in pre-tempered grades such as 6061-O (annealed), tempered grades such as 6061-T6 (solutionized and artificially aged) and 6061-T651 (solutionized, stress-relieved stretched and artificially aged).

Table:-3

Base Material	AA 6061-T6
Density value	2.70 g/cm^3
Young's modulus value	68Gpa
Tensile strength value	124-290 Mpa
Elongation at break value	12-25%
Poisson's ratio value	0.33
Melting temperature value	585°c
Thermal conductivity value	151-202 W/(m.k)
Linear thermal expansion coefficient value	2.32X10^{-5} (K^{-1})
Specific heat capacity value	897 J/(kg. k)

6061-T6

6061-T6 Aluminium Standard Heat Treating Process

T6 temper 6061 has been treated to provide the maximum precipitation hardening (and therefore maximum yield strength) for a 6061 aluminium alloy. It has an ultimate tensile strength of at least 290 MPa (42 ksi) and yield strength of at least 240 MPa (35 ksi). More typical values are 310 MPa (45 ksi) and 270 MPa (39 ksi), respectively.[10] This can exceed the yield strength of certain types of stainless steel.[11] In thicknesses of 6.35 mm (0.250 in) or less, it has elongation of 8% or more; in thicker sections, it has elongation of 10%. T651 temper has similar mechanical properties.

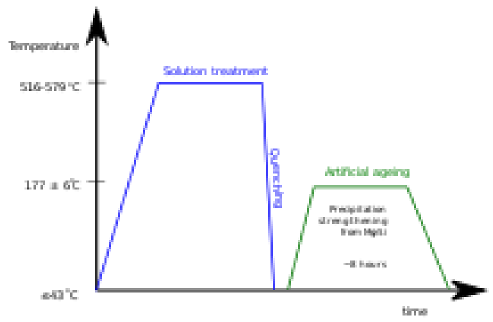


Fig.9 Heat Treating Process

The typical value for thermal conductivity for 6061-T6 at 25 °C (77 °F) is around 152 W/m K. A material data sheet defines the fatigue limit under cyclic load as 97 MPa (14 ksi) for 500,000,000 completely reversed cycles using a standard RR Moore test machine and specimen. Note that aluminium does not exhibit a well-defined "knee" on its S-n graph, so there is some debate as to how many cycles equates to "infinite life". Also note the actual value of fatigue limit for an application can be dramatically affected by the conventional de-rating factors of loading, gradient, and surface finish.

3.4.1 Uses

6061 is commonly used for the following:

- Construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircraft. 2024 alloy is somewhat stronger, but 6061 is more easily worked and remains resistant to corrosion even when the surface is abraded, which is not the case for 2024, which is usually used with a thin Alclad coating for corrosion resistance.
- Yacht construction, including small utility boats.
- Automotive parts, such as the chassis of the Audi A8 and the Plymouth Prowler.
- flashlights
- Aluminium cans for the packaging of food and beverages.
- Scuba tanks and other high pressure gas storage cylinders (post 1995)

6061-T6 is used for:

- Bicycle frames and components.
- middle to high-end recurve risers
- Many fly fishing reels.
- the Pioneer plaque
- the secondary chambers and baffle systems in firearm sound suppressors (primarily pistol suppressors for reduced weight and improved mechanical functionality), while the primary expansion chambers usually require 17-4PH or 303 stainless steel or titanium.[20][21]
- The upper and lower receivers of many non mil-spec AR-15 rifle variants.

- Many aluminium docks and gangways, welded into place.
- material used in some ultra-high vacuum (UHV) chambers
- Many parts for remote controlled model aircraft, notably helicopter rotor components.
- Large amateur radio antennas.
- Fire department rescue ladders

3.4.2 Welding

6061 is highly weldable, for example using tungsten inert gas welding (TIG) or metal inert gas welding (MIG). Typically, after welding, the properties near the weld are those of 6061-T4, a loss of strength of around 40%. The material can be re-heat-treated to restore near -T6 temper for the whole piece. After welding, the material can naturally age and restore some of its strength as well. Most strength is recovered in the first few days to a few weeks. Nevertheless, the Aluminium Design Manual (Aluminium Association) recommends the design strength of the material adjacent to the weld to be taken as 165 MPa/24000 PSI without proper heat treatment after the welding. Typical filler material is 4043 or 5356.

3.5 7075 aluminium alloy

7075 aluminium alloy (**AA7075**) is an aluminium alloy with zinc as the primary alloying element. It has excellent mechanical properties and exhibits good ductility, high strength, toughness, and good resistance to fatigue. It is more susceptible to embrittlement than many other aluminium alloys because of micro segregation, but has significantly better corrosion resistance than the alloys from the 2000 series. It is one of the most commonly used aluminium alloys for highly stressed structural applications and has been extensively used in aircraft structural parts.

7075 aluminium alloy's composition roughly includes 5.6–6.1% zinc, 2.1–2.5% magnesium, 1.2–1.6% copper, and less than a half percent of silicon, iron, manganese, titanium, chromium, and other metals. It is produced in many tempers, some of which are **7075-0**, **7075-T6**, **7075-T651**.

The first 7075 was developed in secret by a Japanese company, Sumitomo Metal, in 1935, but introduced by Alcoa in 1943 and was standardized for aerospace use in 1945. 7075 was eventually used for airframe production in the Imperial Japanese Navy.

3.5.1 Mechanical properties

7075-T6

T6 temper 7075 has an ultimate tensile strength of 510–540 MPa (74,000–78,000 psi) and yield strength of at least 430–480 MPa (63,000–69,000 psi). It has a failure elongation of 5–11%.

The T6 temper is usually achieved by homogenizing the cast 7075 at 450°C for several hours, quenching, and then ageing at 120°C for 24 hours. This yields the peak strength of the 7075 alloys. The strength is derived mainly from finely dispersed eta and eta' precipitates both within grains and along grain boundaries.

Table:-4

Base Material	**AA 7075-T6**
Density value	2.81 g/cm^3
Young’s modulus value	71.1Gpa
Tensile strength value	572 Mpa
Elongation at break value	11%
Poisson’s ratio value	0.33
Melting temperature value	477°c
Thermal conductivity value	130-150 W/(m.k)
Linear thermal expansion coefficient value	2.36X10^{-5} (K^{-1})
Specific heat capacity value	714.8 J/(kg. k)

3.5.2 Uses

The world's first mass-production usage of the 7075 aluminium alloy was for the Mitsubishi A6M Zero fighter. The aircraft was known for its excellent manoeuvrability which was facilitated by the higher strength of 7075 compared to previous aluminium alloys.

7000 series alloys such as 7075 are often used in transport applications due to their high specific strength, including marine, automotive and aviation.[6][12] These same properties lead to its use in rock climbing equipment, bicycle components, inline-skating-frames and hang glider airframes are commonly made from 7075 aluminium alloy. Hobbygrade RC models commonly use 7075 and 6061 for chassis plates. 7075 is used in the manufacturing of M16 rifles for the U.S. military as well as AR-15 style rifles for the civilian market. In particular high-quality M16 rifle lower and upper receivers, as well as extension tubes, are typically made from 7075-T6 alloy. Desert Tactical Arms, SIG Sauer, and French armament company PGM use it for their precision rifles. It is also commonly used in shafts for lacrosse sticks, such as the STX sabre, and camping knife and fork sets. It is a common material used in competition yo-yos as well.

Due to its high strength, low density, thermal properties, and its ability to be highly polished, 7075 is widely used in mold tool manufacturing. This alloy has been further refined into other 7000 series alloys for this application, namely 7050 and 7020.

3.5.3 Aerospace applications

7075 was used in the Space Shuttle SRB nozzles, and the external tank SRB beam in the Inter-tank section.

3.5.4 Applications:

1. Aircraft fittings
2. Gears and shafts
3. Missile parts
4. Regulating valve parts
5. Worm gears
6. Aerospace/defence applications
7. Automotive

3.6 Magnesium alloy

Magnesium alloys are mixtures of magnesium (the lightest structural metal) with other metals (called an alloy), often aluminium, zinc, manganese, silicon, copper, rare earths and zirconium. Magnesium alloys have a hexagonal lattice structure, which affects the fundamental properties of these alloys. Plastic deformation of the hexagonal lattice is more complicated than in cubic latticed metals like aluminium, copper and steel; therefore, magnesium alloys are typically used as cast alloys, but research of wrought alloys has been more extensive since 2003. Cast magnesium alloys are used for many components of modern automobiles and have been used in some high-performance vehicles; die-cast magnesium is also used for camera bodies and components in lenses.

Practically, all the commercial magnesium alloys manufactured in the United States contain aluminium (3 to 13 percent) and manganese (0.1 to 0.4 percent). Many also contain zinc (0.5 to 3 percent) and some are hardenable by heat treatment. All the alloys may be used for more than one product form, but alloys AZ63 and AZ92 are most used for sand castings, AZ91 for die castings, and AZ92 generally employed for permanent mold castings (while AZ63 and A10 are sometimes also used in the latter application as well). For forgings, AZ61 is most used, and here alloy M1 is employed where low strength is required and AZ80 for highest strength. For extrusions, a wide range of shapes, bars, and tubes are made from M1 alloy where low strength suffices or where welding to M1 castings is planned. Alloys AZ31, AZ61 and AZ80 are employed for extrusions in the order named, where increase in strength justifies their increased relative costs.

Magnox (alloy), whose name is an abbreviation for "magnesium non-oxidizing", is 99% magnesium and 1% aluminium, and is used in the cladding of fuel rods in magnox nuclear power reactors.

Magnesium alloys are referred to by short codes (defined in ASTM B275) which denote approximate chemical compositions by weight. For example, AS41 has 4% aluminium and 1% silicon; AZ81 is 7.5% aluminium and 0.7% zinc. If aluminium is present, a manganese component is almost always also present at about 0.2% by weight which serves to improve grain structure; if aluminium and manganese are absent, zirconium is usually present at about 0.8% for this same purpose. Magnesium is a flammable material and must be handled carefully.

3.6.1 Designation

Magnesium alloys names are often given by two letters following by two numbers. Letters tell main alloying elements (A = aluminium, Z = zinc, M = manganese, S = silicon). Numbers indicate respective nominal compositions of main alloying elements. Marking AZ91 for example conveys magnesium alloy with roughly 9 weight percent aluminium and 1 weight percent zinc. Exact composition should be confirmed from reference standards.

The designation system for magnesium alloys is not as well standardized as in the case of steels or aluminium alloys; most producers follow a system using one or two prefix letters, two or three numerals, and a suffix letter. The prefix letters designate the two principal alloying metals according to the following format developed in ASTM specification B275, as shown in the table at right.

Aluminium, zinc, zirconium, and thorium promote precipitation hardening: manganese improves corrosion resistance; and tin improves castability. Aluminium is the most common alloying element. The numerals correspond to the rounded-off percentage of the two main alloy elements, proceeding alphabetically as compositions become standard. Temper designation is much the same as in the case of aluminium. Using –F, -O, -H1, -T4, -T5, and –T6. Sand permanent-mold, and die casting are all well developed for magnesium alloys, die casting being the most popular. Although magnesium is about twice as expensive as aluminium, its hot-chamber die-casting process is easier, more economical, and 40% to 50% faster than cold-chamber process required for aluminium. Forming behaviour is poor at room temperature, but most conventional processes can be performed when the material is heated to temperatures of 450–700 °F (232–371 °C). As these temperatures are easily attained and generally do not require a protective atmosphere, many formed and drawn magnesium products are manufactured. The machinability of magnesium alloys is the best of any commercial metal, and in many applications, the savings in machining costs more than compensate for the increased cost of the material. It is necessary, however, to keep the tools sharp and to provide ample space for the chips. Magnesium alloys can be spot-welded nearly as easily as aluminium, but scratch brushing or chemical cleaning is necessary before the weld is formed. Fusion welding is carried out most easily by processes using an inert shielding atmosphere of argon or helium gas. Considerable misinformation exists regarding the fire hazard in processing magnesium alloys. It is true that magnesium alloys are highly combustible when in a finely divided form, such as powder or fine chips, and this hazard should never be ignored. Above 800 °F (427 °C), a non-combustible, oxygen-free atmosphere is required to suppress burning. Casting operations often require additional precautions because of the reactivity of magnesium with sand and water in sheet, bar, extruded or cast form; however, magnesium alloys present no real fire hazard.

Thorium-containing alloys are not usually used, since a thorium content of more than 2% requires that a component be handled as a radioactive material, although thoriated magnesium known as Mag-Thor was used in military and aerospace applications in the 1950s.

Magnesium alloys are used for both cast and forged components, with the aluminium-containing alloys usually used for casting and the zirconium-containing ones for forgings; the zirconium-based alloys can be used at higher temperatures and are popular in aerospace.

Magnesium + yttrium + rare-earth + zirconium alloys such as WE54 and WE43 (the latter with composition Mg 93.6%, Y 4%, Nd 2.25%, 0.15% Zr) can operate without creep at up to 300C and are reasonably corrosion-resistant.

3.6.2 Characteristics:

Magnesium's particular merits are similar to those of aluminium alloys: low specific gravity with satisfactory strength. Magnesium provides advantages over aluminium, in being of even lower density (approx. 1800 kg/m^3) than aluminium (about 2800 kg/m^3). The mechanical properties of magnesium alloys tend to be below those of the strongest of the aluminium alloys.

The strength-to-weight ratio of the precipitation-hardened magnesium alloys is comparable with that of the strong alloys of aluminium or with the alloy steels. Magnesium alloys, however, have a lower density, stand greater column loading per unit weight and have a higher specific modulus. They are also used when great strength is not necessary, but where a thick, light form is desired, or when higher stiffness is needed. Examples are complicated castings, such as housings or cases for aircraft, and parts for rapidly rotating or reciprocating machines. Such applications can induce cyclic crystal twinning and detwinning that lowers yield strength under loading direction change.

The strength of magnesium alloys is reduced at somewhat elevated temperatures; temperatures as low as 200 °F (93 °C) produce considerable reduction in the yield strength. Improving the high-temperature properties of magnesium alloys is an active research area with promising results.

Magnesium alloys show strong anisotropy and poor formability at room temperature stemming from their hexagonal close-packed crystal structure, limiting practical processing modes. At room temperature, basal plane slip of dislocation and mechanical crystal twinning are the only operating deformation mechanisms; the presence of twinning additionally requires specific loading conditions to be favourable. For these reasons processing of magnesium alloys must be done at high temperatures to avoid brittle fracture.

The high-temperature properties of magnesium alloys are relevant for automotive and aerospace applications, where slowing creep (deformation) plays an important role in material lifetime. Magnesium alloys generally have poor creep properties; this shortcoming is attributed to the solute additions rather than the magnesium matrix since pure magnesium shows similar creep life as pure aluminium, but magnesium alloys show decreased creep life compared to aluminium alloys. Creep in magnesium alloys occurs mainly by dislocation slip (materials science), activated cross slip, and grain boundary sliding. Addition of small amounts of zinc in Mg-RE alloys has been shown to increase creep life by 600% by stabilizing precipitates on both basal and prismatic planes through localized bond stiffening. These developments have allowed for magnesium alloys to be used in automotive and aerospace applications at relatively high temperatures. Microstructural changes at high temperatures are also influenced by Dynamic recrystallization in fine-grained magnesium alloys.

Individual contributions of gadolinium and yttrium to age hardening and high temperature strength of magnesium alloys containing both elements are investigated using alloys containing different Gd : Y mole ratios of 1:0, 1:1, 1:3, and 0:1 with a constant Y + Gd content of 2.75 mol%. All investigated alloys exhibit remarkable age hardening by precipitation of β phase with DO19 crystal structure and β phase with BCO crystal structure, even at aging temperatures higher than 200 °C. Both precipitates are observed in peak-aged specimens. The precipitates contributing to age hardening are fine and their amount increases as Gd content increases, and this result in increased peak hardness, tensile strength and 0.2% proof stress but decreased elongation. On the other hand, higher Y content increases the elongation of the alloys but results in decreased strength.

Despite the active nature of the metal, magnesium and its alloys have good resistance to corrosion in air at STP. The rate of corrosion is slow compared with rusting of mild steel in the same atmosphere. Immersion in salt water is problematic, but a great improvement in resistance to salt-water corrosion has been achieved, especially for wrought materials, by reducing some impurities particularly nickel and copper to very low proportions or using appropriate coatings.

CHAPTER-4

MODELLING

4 MODELLING

4.1 INTRODUCTION TO SOLIDWORKS:

Individual parts or components, allowing the easy construction of assemblies. Solid Works also include Solid Works is a 3D mechanical CAD (Computer Aided Design) program that runs on Microsoft windows and is being developed by Dassault Systems., a subsidiary of Dassault Systems, S.A. (Velizy France). Solid Works is currently used by over 1.3 million engineers and designers at more than 130,000 companies worldwide.

Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometry parameters such as tangent, parallel, concentric, horizontal or vertical, etc.,

Design intent is how the creator of the part wants it to respond to changes and updates. For example, you would want the hole at the top of a beverage can to stay at the top surface, regardless of the height or size of the can. Solid Works allows you to specify that the hole is a feature on the top surface, and will then honor your design intent no matter what the height you later gave to the can.

Features refer to the building blocks of the part. They are the shaped end operations that construct the part. Shape-based features typically began with a 2D or 3D sketch of shapes such as bosses, holes, slots, etc. This shape is then extruded or cut to add or remove material from the part. Operation-based features are not sketch-based, and include features such as fillets, chamfers, shells, applying draft to the faces of a part, etc.

Building a model in Solid Works usually starts with a 2D sketch (although the 3D sketches are available for power users). The sketch consists of geometry such as points, lines, arcs, conics (except the hyperbola), Splines. Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity, and concentricity. The parametric nature of solid works means that the dimensions and relations drive the geometry, not the other way around. The dimensions in the sketch can be controlled independently, or by relationships to other parameters inside or outside of the sketch.

In an assembly, the analog to sketch relations are mates. Just sketch relations define conditions such as tangency, parallelism and concentricity with respect to sketch geometry, assembly mates define equivalent relations with respect to the additional advanced mating features such as gear and cam-follower mates, which allow modeled gear assemblies to accurately reproduce the rational movement of an actual gear train.

Finally, Drawing can be created either from parts or assemblies. Views are automatically generated from the solid model, and nodes, dimensions and tolerances can then be easily added to the drawing as needed. The drawing module includes most paper sizes and standards (ANSI, ISO, DIN, GOST, JIS, BSI and SAC).

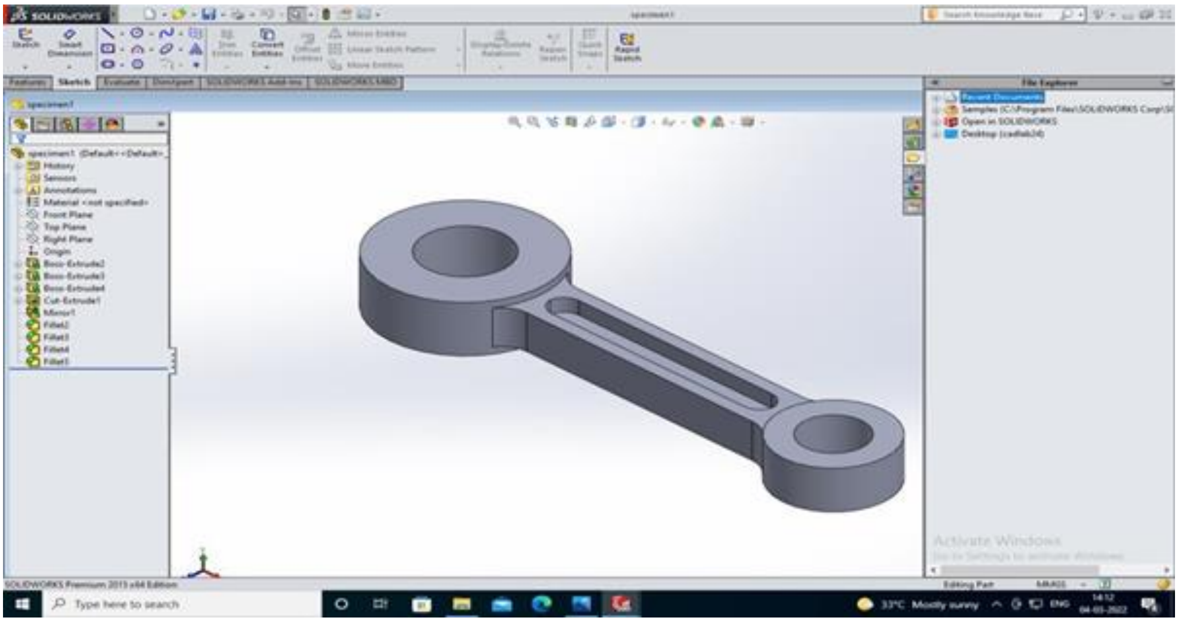


Fig.10 Connecting Rod Design in SolidWorks

4.1.1 Design validation tools

Solid Works Simulation is a design validation tool that shows engineers how their designs will behave as physical objects.

Solid Works Motion is a virtual prototyping tool that provides motion simulation capabilities to ensure design function properly.

Solid Works Flow Simulation is a tool that tests internal and external fluid-flow simulation and thermal analysis so designers can conduct tests on virtual prototypes.

Solid Works Simulation Premium is a Finite Element Analysis (FEA) design validation tool that can handle some multi physics simulations as well as nonlinear materials.
Solid Works Sustainability is a product that measures the environmental impact of designs while they are modeled in Solid Works.

4.1.2 CAD Productivity Tools

Solid Works Toolbox is a library of parts that uses "Smart Part" Technology to automatically select fasteners and assemble them in the desired sequence.

Solid Works Utilities is software that lets designers find differences between two versions of the same parts, or locate, modify, and suppress features within a model.

Feature Works is feature recognition software that lets designers make changes to static geometric data, increasing the value of translated files. With Feature Works, designers can preserve or introduce new design intent when bringing 3D models created in other software into the Solid Works environment.

4.1.3 Specialty Design Tools

Solid Works Routing

Mold flow Xpress is a mold design validation tool that was built into a solid modelling environment. It enables mold designers to quickly and easily validate whether a plastic injection-molded part can be filled.

Solid Works Mold Base is a catalogue of standard mold base assemblies and components. The package enables designers to generate a completely assembled mold base.

Print3D is a 30-printing feature that allows users to convert their 30 CAD model to a .STL file and then have it sent to specialty manufacturers for quote. The .STL files can be used to generate an instant binding quoted using the Quick quote technology.

Drive Works Xpress Drive Works Xpress is rules-based design automation tool for engineers to create multiple variations of parts, assemblies and drawings quickly and accurately.

Solid Works files use the Microsoft Structured Storage file format. This means that there are various files embedded within each SLDDRW (drawing files), SLDPRT (part files), SLDASM (assembly files) file, including preview bitmaps and metadata sub-files. Various third-party tools (see COM Structured storage) can be used to extract these sub-files, although the sub files in many cases use proprietary binary file formats.

The model of the connecting rod has been designed using Solid works software. The design of the model has been done m two different stages.

I. Part designing

In this stage, the connecting rod is designed with the required dimensions.

2. Assembly

The 3D model is created, by using various modelling operations like extrude, sweep, revolve, etc.

CHAPTER-5

ANALYSIS

5 ANALYSIS

5.1 Introduction to ANSYS workbench

ANSYS Workbench is the framework upon which the industry's broadest suite of advanced engineering simulation technology is built. An innovative project schematic view ties together the entire simulation process, guiding the user every step of the way. Even complex multi physics analyses can be performed with drag-and-drop simplicity.

The ANSYS Workbench platform automatically forms a connection to share the geometry for both the fluid and structural analyses, minimizing data storage and making it easy to study the effects of geometry changes on both analyses. ln addition, a connection is formed to automatically transfer pressure loads from the fluid analysis to the structural analysis.

The ANSYS Workbench interface is arranged into two primary areas: The toolbox and the project Schematic. The toolbox contains the system templates that you can use to build a project. The project Schematic is the area if the interface where you will manage your project. In addition, you will see a menu bar and a toolbar with frequently used functions. You can also use context menus, accessible via a right-mouse click, on schematic items, and cells. Context menus provide capabilities to add to and modify projects.

A typical ANSYS analysis has three distinct steps

- Build the model
- Apply loads and obtain the solution
- Review the results

Building a Model

Building a finite element model requires more of an ANSYS user's time than any other part of the analysis. First, you specify a job name and analysis title.

Apply loads and obtain the solution

In this step, you use the SOLUTION processor to define the analysis type and analysis options, apply loads, specify load step options, and initiate the finite element solution. You also can apply loads using the PREP7 pre-processor.

Review the results

Once the solution has been calculated, you can use the ANSYS postprocessors to review the results. Two postprocessors are available-POST 1 and POST26

5.1.1 ANSYS Workbench Features:

- Bidirectional, parametric links with all major CAD systems.
- Integrated, analysis-focused geometry modelling, repair, and simplification via ANSYS Design Modeller.
- Highly-automated, physics-aware meshing.
- Automatic contact detection.
- Unequalled depth of capabilities within individual physics disciplines.
- Unparalleled breadth of simulation technologies.
- Complete analysis systems that guide the user start-to-finish through an analysis.
- Comprehensive multi physics simulation with drag-and-drop ease of use.
- Flexible components enable tools to be deployed to best suit engineering intent.
- Innovative project schematic view allows engineering intent, data relationships, and the state of the project to be comprehended at a glance.
- Complex project schematics can be saved for re-use.
- Pervasive, project-level parameter management across all physics.
- Automated what-if analyses with integrated design point capability.
- Adaptive architecture with scripting and journaling capabilities and API" s enabling rapid integration of new and third-party solutions.

5.1.2 Materials:

A large part of a fatigue analysis is getting an accurate description of the fatigue material properties. Since fatigue is so empirical, sample fatigue curves are included only for structural steel and aluminium materials. These properties are included as a guide only with intent for the user to provide his/her own fatigue data for more accurate analysis. In the case of assemblies with different materials, each part will use its own fatigue material properties just as it uses its own static properties (like modulus of elasticity).

5.1.3 Stress-life Data Options/Features:

- Fatigue material data stored as tabular alternating stress vs. life points.
- Options to have log-log, semi-log, or linear interpolation.
- Ability to graphically view the fatigue material data.
- The fatigue data is saved in XML format along with the other static material data.

5.2 Analysis:

The Solid model is converted into a FEM model and the results are obtained after applying the structural boundary conditions. The loads and the constraints are imposed on this FEM model. The element used for analysis is 4 noded tetrahedral elements. The model is meshed with 15257 elements and 26804 nodes.

A) Loading:

Fatigue, by definition, is caused by changing the load on a component over time. Thus, unlike static stress safety tools, which perform calculations for a single stress state, fatigue damage occurs when the stress at a point change over time.

There are essentially 4 classes of fatigue loading with the fatigue tool currently supporting the first 3:

- Constant amplitude, proportional loading
- Non-constant amplitude, proportional loading
- Constant Amplitude, non-proportional loading
- Non-constant amplitude, non-proportional loading

B) Load Effects:

Fatigue material tests are usually conducted in a uni axial loading under a fixed or zero mean stress state. It is cost-prohibitive to conduct experiments that capture all mean stress, loading, and surface conditions. Thus, part of the duty of the fatigue tool is to convert the FEM stresses and fatigue loads into a form that can be used to query fatigue material data.

C) Miscellaneous Analysis options:

Fatigue material property tests are usually conducted under very specific and controlled conditions (e.g., axial loading, polished specimens, .5-inch gauge diameter). If the service part conditions differ from as tested, modification factors can be applied to try to account for the difference. The user may also specify a scale factor that will scale all stresses, both alternating and mean by the specified value. This value may be parameterized. Applying a scale factor is useful to avoid having to solve the static model again to see the effects of changing the magnitude of the FEM loads. In addition, this factor may be useful to convert a non-constant amplitude load history data into the appropriate values.

5.3 Results Output:

Several results for evaluating fatigue are available to the user. Some are contour plots of a specific result over the model while others give information about the most damaged point in the model (or the most damaged point in the scope of the result). Outputs are listed and described in detail below.

- Fatigue Life
- Damage at a specified design life
- Factor of safety at a specified design life
- Stress biaxiality
- Equivalent alternating stress
- Fatigue sensitivity chart

A) Contour plot of available life over the model:

This result can be over the whole model or scoped to a given part or surface. In addition to this and any contour result may be exported to a tab-delimited text file by a RMB click on the result. This result contour plot shows the available life for the given fatigue analysis. If loading is of constant amplitude, this represents the number of cycles until the part will fail due to fatigue. If loading is non-constant, this represents the number of loading blocks until failure. Thus, if the given load history represents one month of loading and the life was found to be 120, the expected model life would be 120 months. In a constant amplitude analysis, if the alternating stress is lower than the lowest alternating stress defined in the S-N curve, the life at that point will be used.

B) Fatigue Damage:

This is a contour plot of the fatigue damage at a given design life. Fatigue damage is defined as the design life divided by the available life. This result may be scoped. The default design life may be set through the Control Panel.

C) Safety Factor:

This is a contour plot of the factor of safety with respect to a fatigue failure at a given design life. The maximum FS reported is 15. Like damage and life, this result may be scoped. This calculation is iterative for non-constant amplitude loading and may substantially increase solve time.

D) Stress biaxiality contour plot over the model:

As mentioned previously, material properties are uniaxial but stress results are usually multi axial. This result gives the user some idea of the stress state over the model and how to interpret the results. Biaxiality indication is defined as the principal stress smaller in magnitude divided by the larger principal stress with the principal stress nearest zero ignored. When using the biaxiality plot along with the safety factor plot above. it can be seen that the most damaged point occurs at a point of nearly pure shear. Note that for non-proportional fatigue loading, there are multiple stress states and thus there is no single stress biaxiality at each node. Thus, a small standard deviation indicates a condition where the loading is near proportional while a larger deviation indicates change in the direction of the principal stress vectors. This information can be used to give the user additional confidence in his results or whether more in-depth fatigue analysis need be performed to better account for any non-proportionality.

E) Equivalent Alternating Stress:

This is a contour plot of the equivalent alternating stress over the model. In a fatigue analysis, one always needs to query an SN curve to relate the fatigue life to the stress state. Thus the “equivalent alternating stress” is the stress used to query the fatigue SN curve after accounting for fatigue loading type, mean stress effects, multi axial effects, and any other factors in the fatigue analysis. Thus in a fatigue analysis, the equivalent alternating stress can be thought of as an intermediate result that is calculated in the process of finding the fatigue life. The usefulness of this result is that it performs the fatigue related calculations independent of any fatigue material properties.

F) Fatigue Sensitivity Chart:

This chart shows how the fatigue results change as a function of the loading at the critical location on the model. This result may be scoped to parts or surfaces. Sensitivity may be found for life, damage, or factor of safety. The user may set the number of fill points as well as the load variation limits. For example, the user may wish to see the sensitivity of the model's life if the toad was 50% of the current load up to if the load 150% of the current load. (The x-value of I on the graph corresponds to the life at the current loading of the model; The x-value at I .5 corresponds to the critical fatigue life if the finite element loads were 50% higher than they are currently, etc....).

5.4 BUCKLING ANALYSIS:

5.4.1 Methodology

- For the Buckling analysis dimensions and sketch of connecting rod are taken from the reference paper. Buckling analysis is performed analytically and critical buckling stress is calculated using Rankine's formula to manufacture the connecting rod. Then the model of connecting rod is prepared using Solid works software. Then model is exported to ANSYS Workbench software and critical buckling stress is calculated using ANSYS.

Buckling Analysis

- Connecting rod is use to convert reciprocating motion into rotary motion. The design of connecting rod is always based upon buckling load. Connecting rod is subjected to tensile load as well as compressive load. When compressive load acts on a connecting rod it may fracture if compressive load acts on a connecting rod is more than its resisting compressive strength.

- Also if the length of connecting rod is increased above its sectional dimension i.e. if slenderness ratio is more than 40, then the connecting rod gets buckle for the lower value of compressive load which is known as critical buckling load and the stress developed due to this load is called critical buckling stress. The slenderness ratio [ratio of length of column to least radius of gyration] is the important deciding radius for the design of connecting rod. If the ratio is less than 40, design of connecting rod is based on compressive load and if this ratio is more than 40 the design the connecting rod will be based upon buckling load which will be based less than compressive strength of connecting rod. Buckling analysis is performed on the "I" section of connecting rod. The "I" section connecting rod is preferred because the connecting rod can buckle about X axis and Y axis. In connecting rod we assume both ends of connecting rod are hinged about x axis and there are fixed about y axis. The relation between area moment or inertia of x axis and y axis i.e. $I_{xx} = 4I_{yy}$ must be satisfied which is satisfied by "I" section. Therefore mostly I section connecting rod is preferred.

5.5 **MODAL ANALYSIS** :

Modal analysis is the study of the dynamic properties of systems in the frequency domain. Modal analysis calculates the natural frequencies of the system alone. Modal is the simplest analysis and the only thing it does give is the "Resonance frequencies" of the geometry. It is not related to a loading at this stage, only to the geometry. Resonance frequencies change due to the shape of your model and the way it is constrained only. In physics, resonance is a phenomenon in which a vibrating system or external force drives another system to oscillate with greater amplitude at specific frequencies. Frequencies at which the response amplitude is a relative maximum are known as the system's resonant frequencies or resonance frequencies.

The following is the procedure followed for modal analysis:

- The assembled part files from SolidWorks is first to be imported through the IGES format.
- The imported model is given the proper connections for the meshing process.
- Once the connections are done, the part has to be meshed.

- The mesh that has been selected is fine mesh with a relevance of 1 and adaptive curvature.
- The type of mesh may be varied depending on accuracy and computer's processing power.
- The analysis settings are set for modal analysis of six nodes and the required solutions are added.
- The solution is evaluated for all the six nodes and the natural frequency are obtained.
- The natural frequencies of the above materials are compared to find out which one is better.

CHAPTER-6

RESULTS

6 RESULTS

6.1 Medium Carbon Steels

1) 42CrMo4

2) AISI 1141 Steel as Rolled

3) AISI 1141 Steel Cold Drawn

4) C-70

6.2 Aluminium Alloys

1) AL 2024-T3

2) AA 6061-T6

3) AA 7075-T6

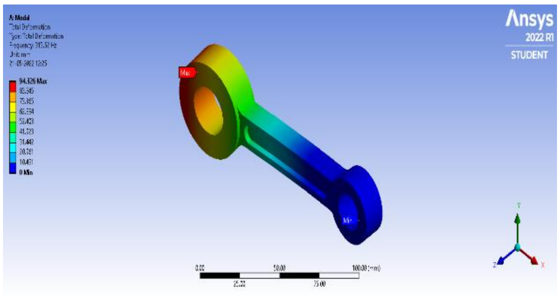
6.3 Magnesium Alloy

6.1.1 Medium Carbon Steel:(42CrMo4)

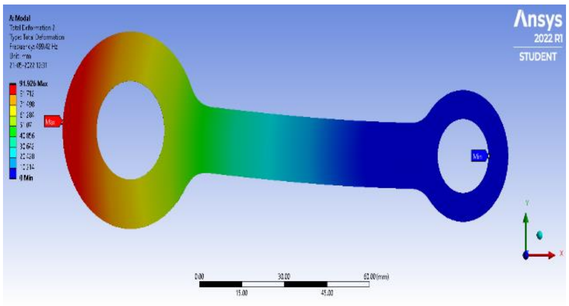
Table:-5

Modes	Frequency (Hz)	Total Deformation(mm)
1	313.52	94.326
2	499.42	91.926
3	1057.9	129.27
4	2863.6	107.88
5	3732	93.536
6	6135.1	77.213

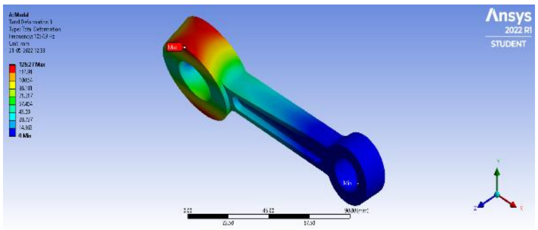
Mode-1:-Frequency(313.52)Hz



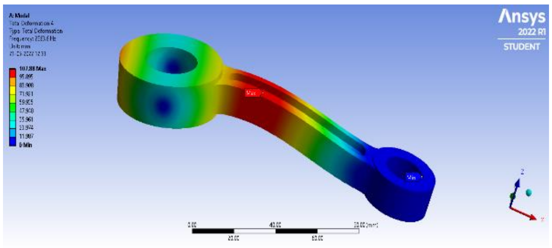
Mode-2:-Frequency(499.42)Hz



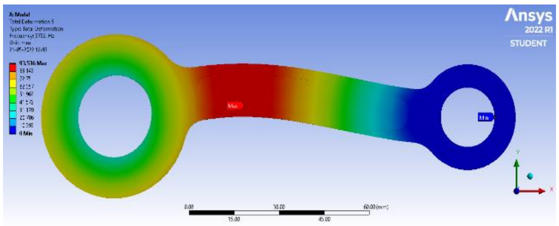
Mode-3:-Frequency(1057.9)Hz



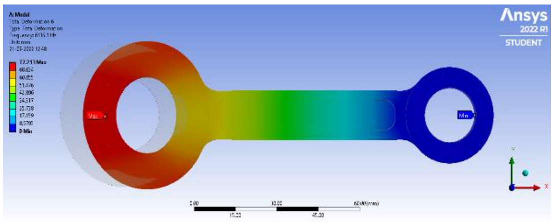
Mode-4:-Frequency(2863.6)Hz



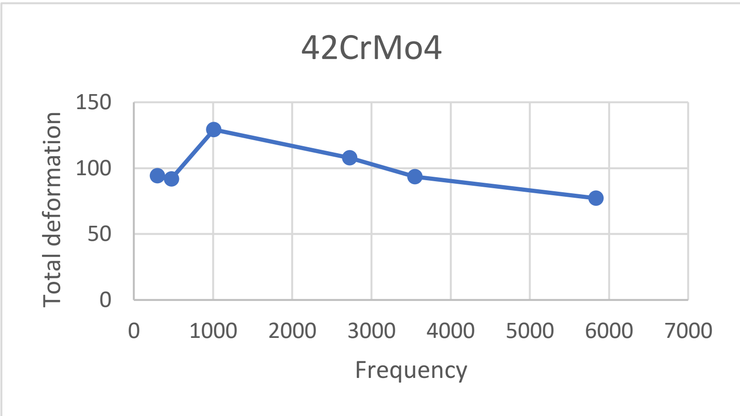
Mode-5:-Frequency(3732)Hz



Mode-6:-Frequency(6135.1)Hz



Graph (Frequency Vs Total Deformation)



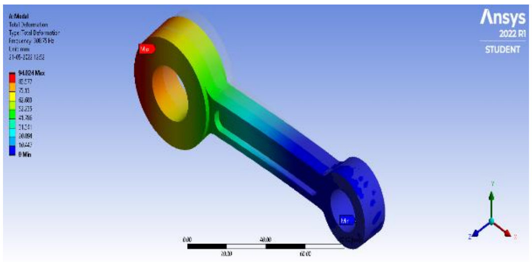
Line Graph 1

6.1.2 **Medium Carbon Steel:**(AISI 1141 Steel as Rolled)

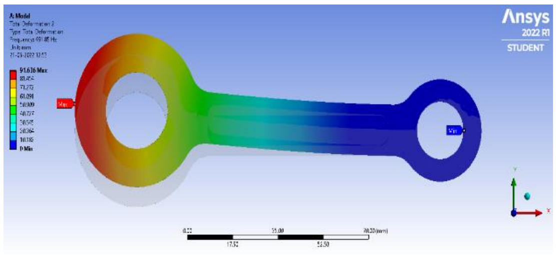
Table:6

Modes	Frequency (Hz)	Total Deformation(mm)
1	308.75	94.024
2	491.85	91.636
3	1045.4	128.86
4	2820.2	107.51
5	3676.5	93.205
6	6041	76.955

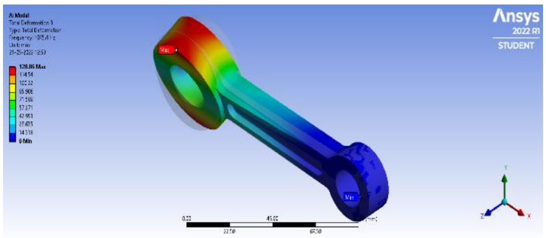
<u>Mode-1</u>:-Frequency(308.75)Hz



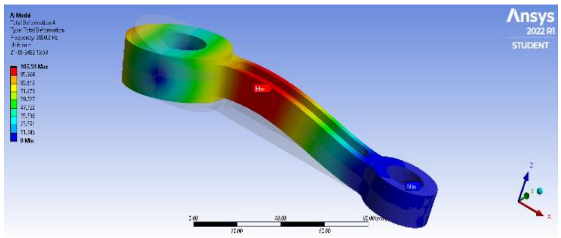
<u>Mode-2</u>:-Frequency(491.85)Hz



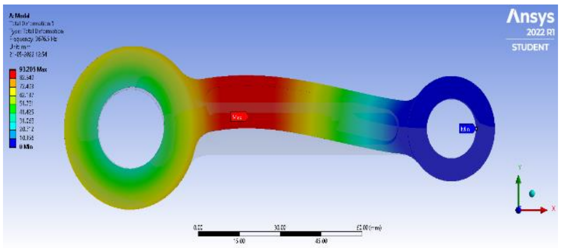
<u>Mode-3</u>:-Frequency(1045.4)Hz



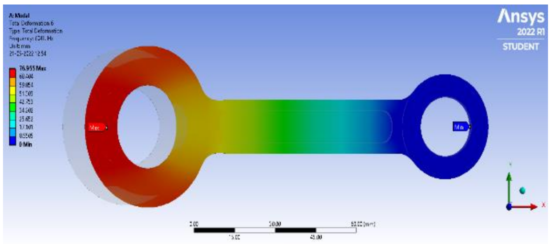
<u>Mode-4</u>:-Frequency(2820.2)Hz



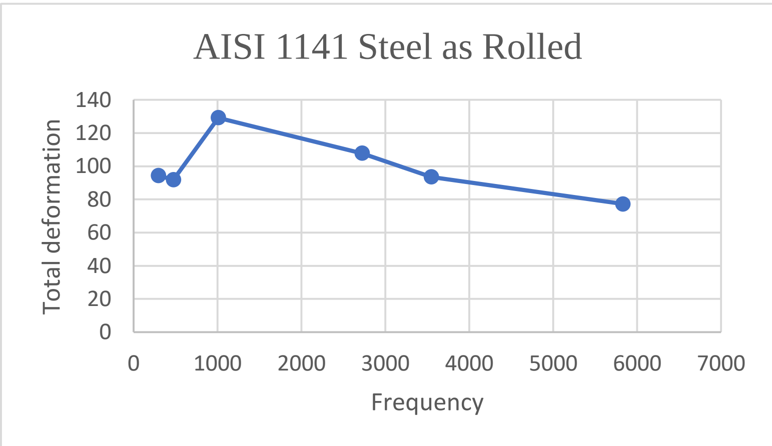
<u>Mode-5</u>:-Frequency(3676.5)Hz



<u>Mode-6</u>:-Frequency(6041)Hz



Graph (Frequency Vs Total Deformation)



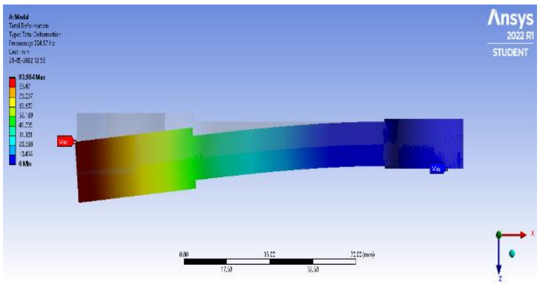
Line Graph

6.1.3 **Medium Carbon Steel:(** AISI 1141 Steel Cold Drawn**)**

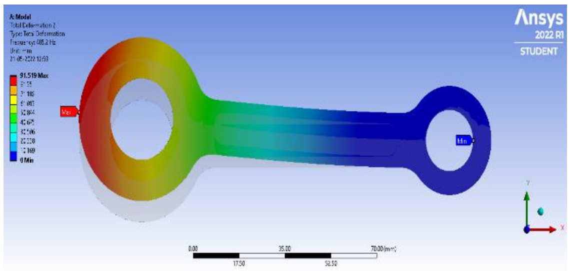
Table:7

Modes	Frequency (Hz)	Total Deformation(mm)
1	304.57	93.904
2	485.2	91.519
3	1031.3	128.69
4	2782	107.37
5	3626.8	93.087
6	5959.3	76.857

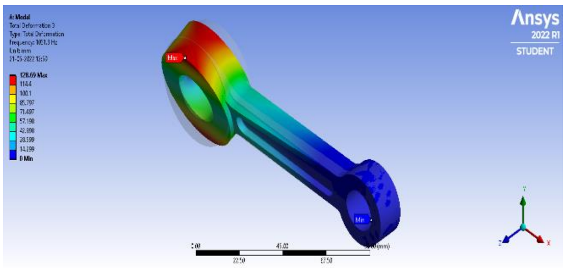
Mode-1:-Frequency(304.57)Hz



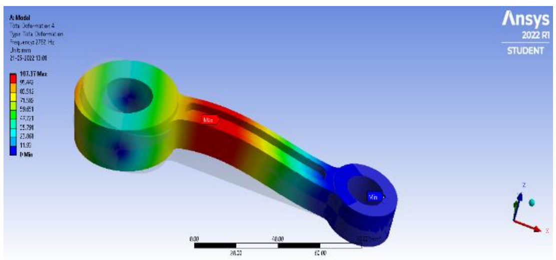
Mode-2:-Frequency(485.2)Hz



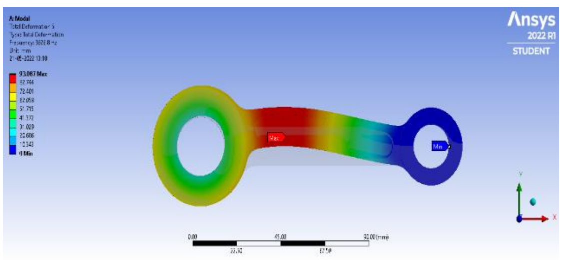
Mode-3:-Frequency(1031.3)Hz



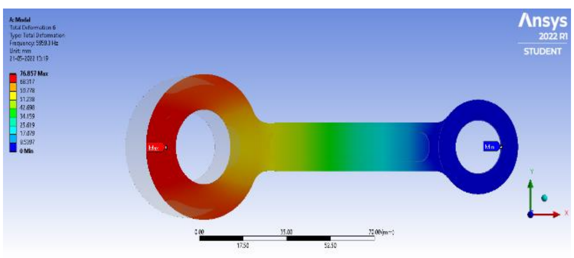
Mode-4:-Frequency(2782)Hz



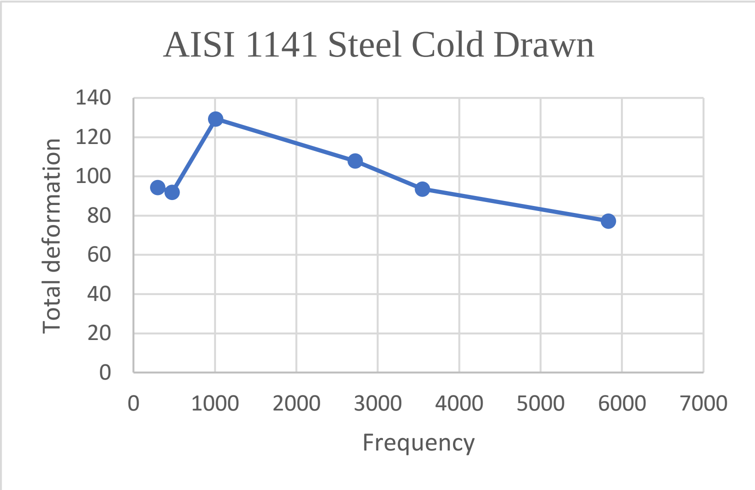
Mode-5:-Frequency(3626.8)Hz



Mode-6:-Frequency(5959.3)Hz



Graph (Frequency Vs Total Deformation)



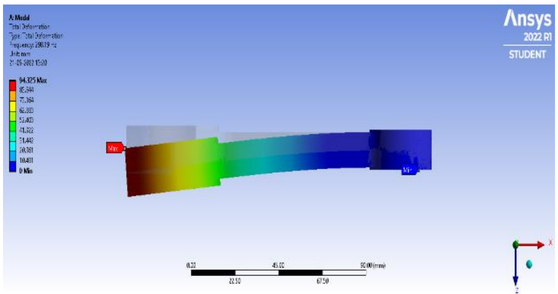
Line Graph

6.1.4 <u>Medium Carbon Steel</u>:(C-70)

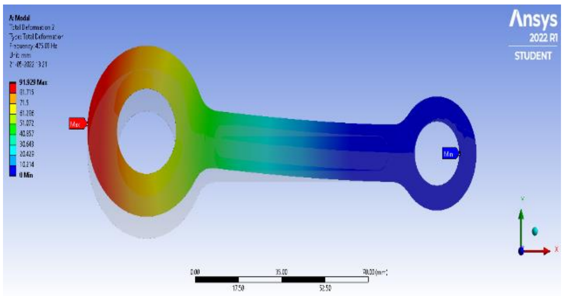
Table:8

Modes	Frequency (Hz)	Total Deformation(mm)
1	298.19	94.325
2	475.03	91.929
3	1009.7	129.27
4	2723.7	107.85
5	3550.8	93.504
6	5834.4	77.201

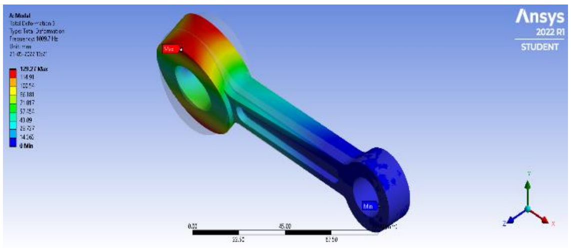
<u>Mode-1</u>:-Frequency(298.19)Hz



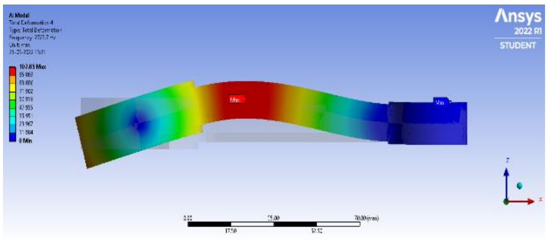
<u>Mode-2</u>:-Frequency(475.03)Hz



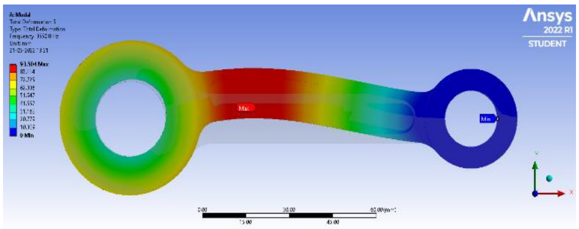
Mode-3:-Frequency(1009.7)Hz



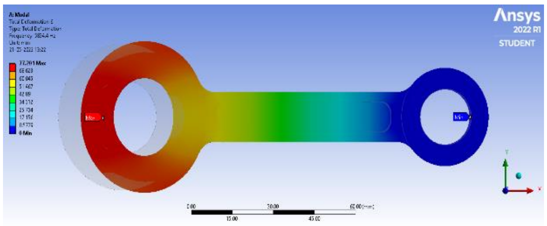
Mode-4:-Frequency(2723.7)Hz



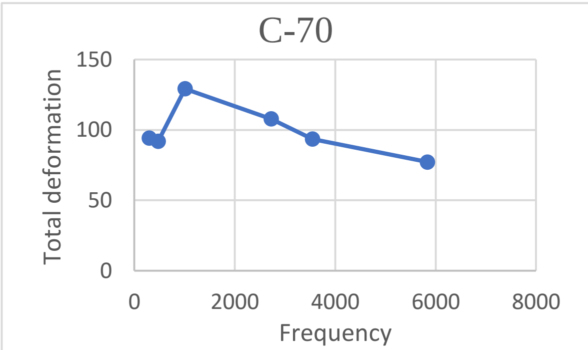
Mode-5:-Frequency(3550.8)Hz



Mode-6:-Frequency(5834.4)Hz



Graph (Frequency Vs Total Deformation)



Line Graph

Observation:

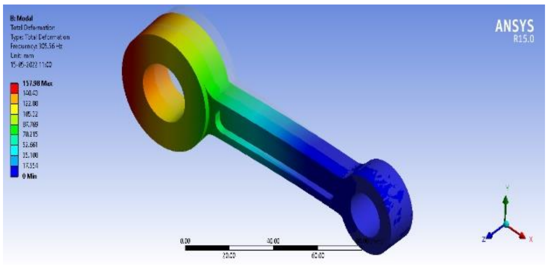
From the above results and values obtained, we observed that in the list of Medium Carbon Steels **42CrMo4** has the highest Natural Frequency at Mode 1 and the rest of the modes. Least Deformed Carbon Steel at mode 6 is AISI 1141 Steel Cold Drawn with Total Deformation of 76.857mm at a Frequency of 5959.3Hz.This is the reason, that Carbon Steels especially Medium Carbon Steels are used for the making of Connecting Rod.

6.2.1 Aluminium Alloy:(AL 2024-T3)

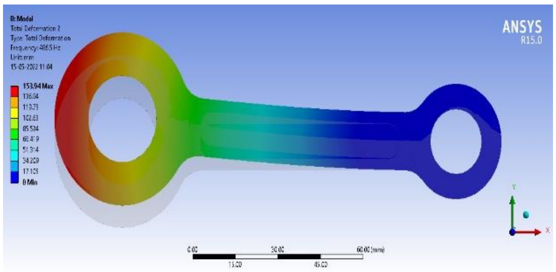
Table:-9

Modes	Frequency (Hz)	Total Deformation(mm)
1	305.56	157.98
2	486.5	153.94
3	1015.8	216.47
4	2790	180.78
5	3632.5	156.9
6	5978.4	129.41

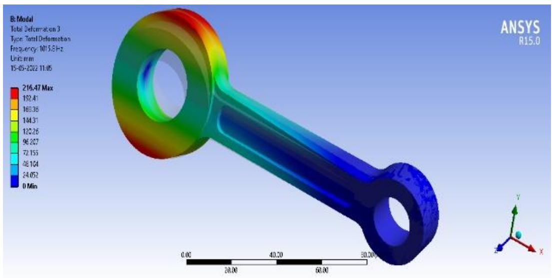
Mode-1:-Frequency(305.56)Hz



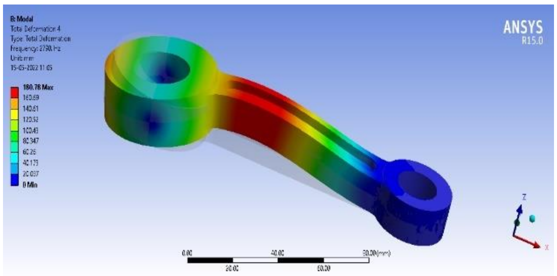
Mode-2:-Frequency(486.5)Hz



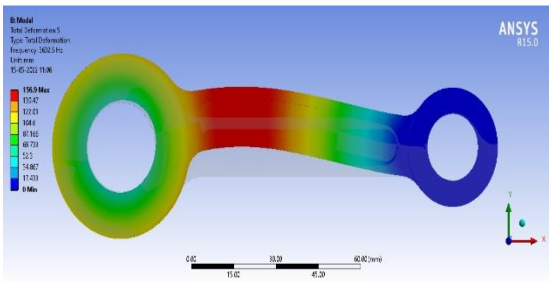
Mode-3:-Frequency(1015.8)Hz



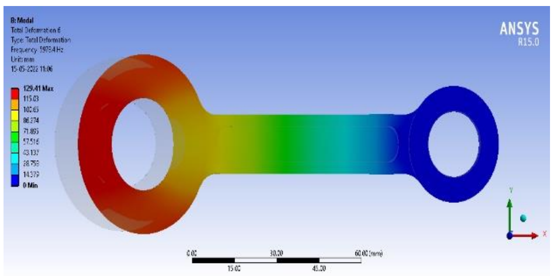
Mode-4:-Frequency(2790)Hz



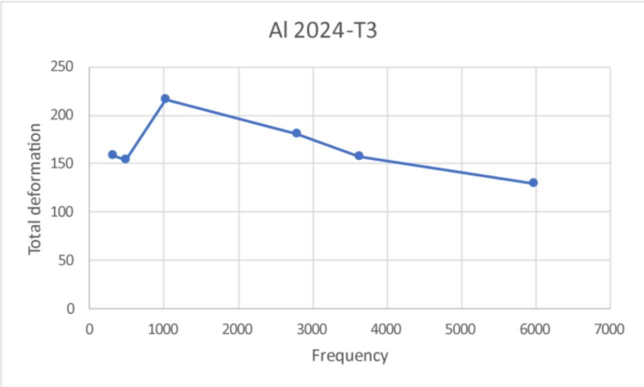
Mode-5:-Frequency(3632.5)Hz



Mode-6:-Frequency(5978.4)Hz



Graph (Frequency Vs Total Deformation)



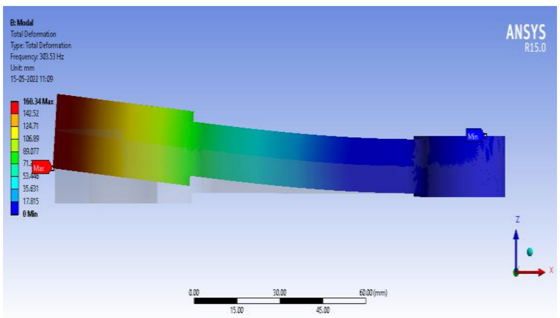
Line Graph 2

6.2.2 <u>Aluminium Alloy</u>:(AA 6061-T6)

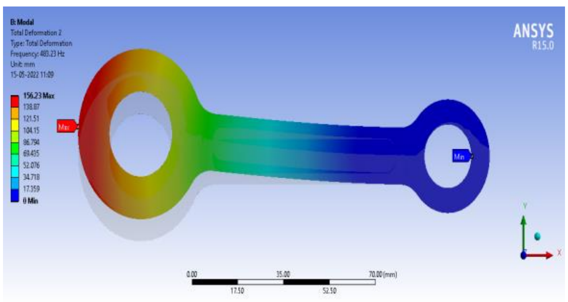
Table:-10

Modes	Frequency (Hz)	Total Deformation(mm)
1	303.53	160.34
2	483.23	156.23
3	1005.6	219.69
4	2771.4	183.53
5	3606.9	159.29
6	5939.2	131.36

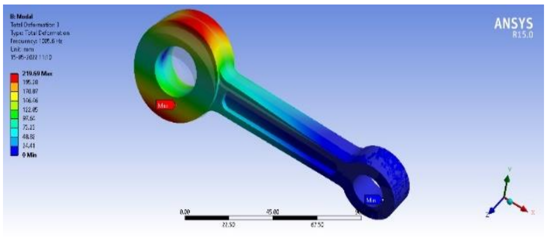
<u>Mode-1</u>:-Frequency(303.53)Hz



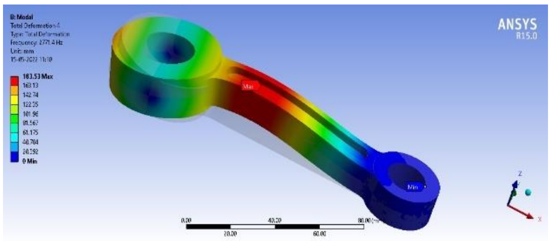
<u>Mode-2</u>:-Frequency(483.23)Hz



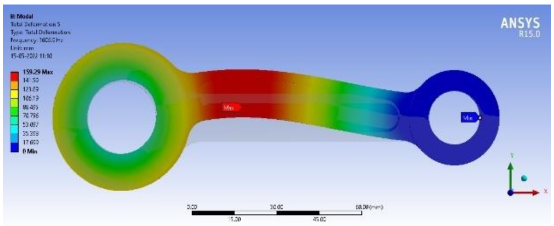
Mode-3:-Frequency(1005.6)Hz



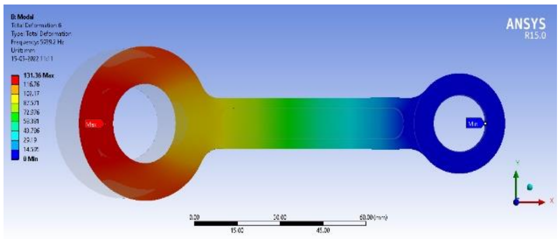
Mode-4:-Frequency(2771.4)Hz



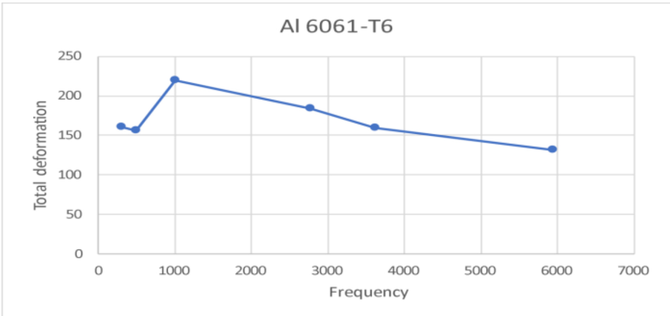
Mode-5:-Frequency(3606.9)Hz



Mode-6:-Frequency(5939.2)Hz



Graph (Frequency Vs Total Deformation)



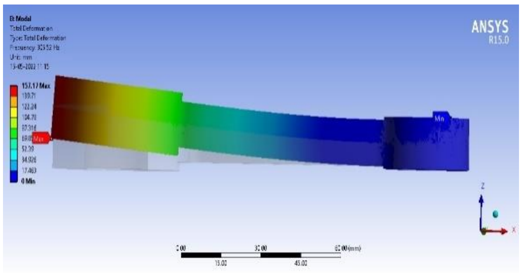
Line Graph 3

6.2.3 Aluminium Alloy:(AA 7075-T6)

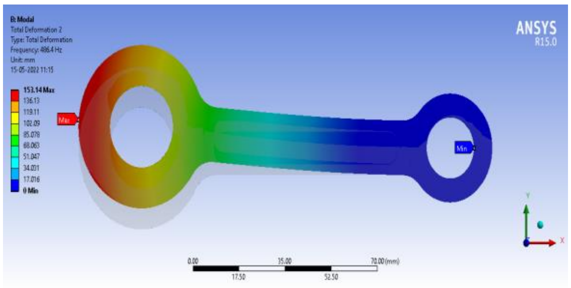
Table:-11

Modes	Frequency (Hz)	Total Deformation(mm)
1	305.52	157.17
2	486.4	153.14
3	1012.2	215.35
4	2789.5	179.9
5	3630.5	156.14
6	5978.1	128.76

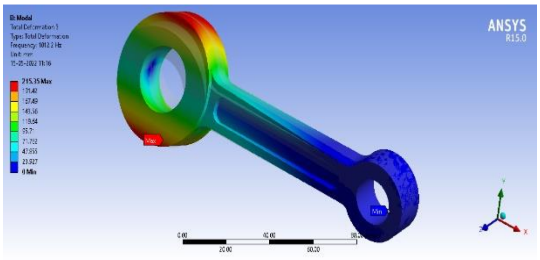
Mode-1:-Frequency(305.52)Hz



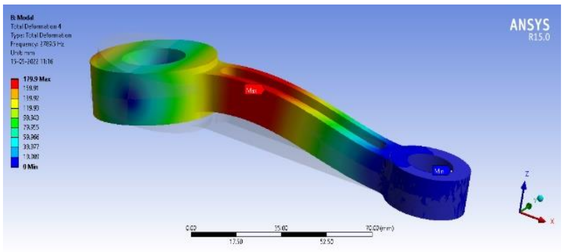
Mode-2:-Frequency(486.4)Hz



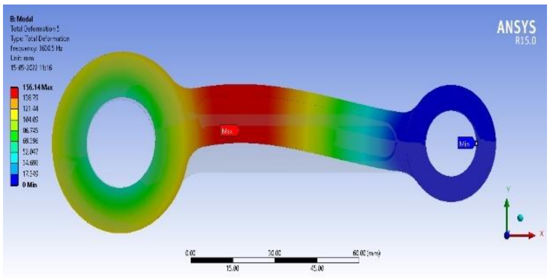
Mode-3:-Frequency(1012.2)Hz



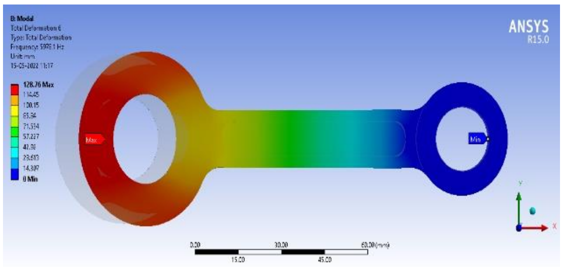
Mode-4:-Frequency(2789.5)Hz



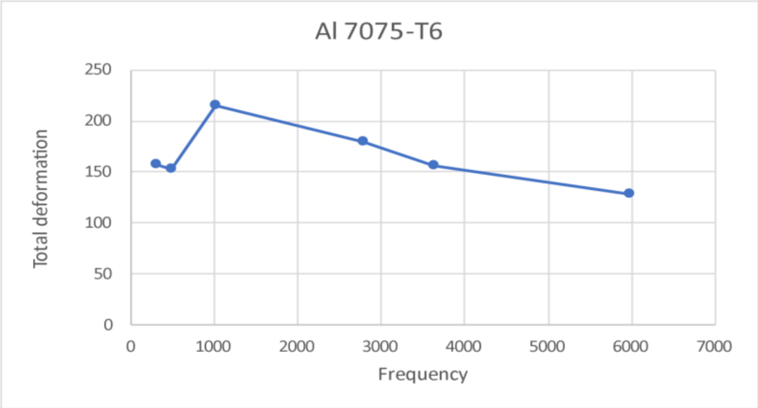
Mode-5:-Frequency(3630.5)Hz



Mode-6:-Frequency(5978.1)Hz



Graph (Frequency Vs Total Deformation)



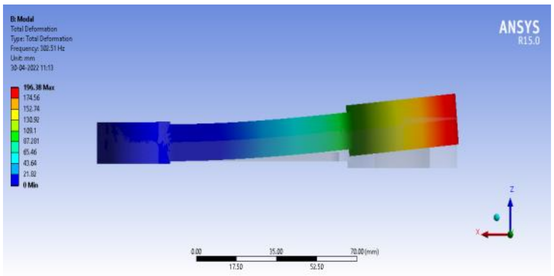
Line Graph 4

6.3 Magnesium Alloy:

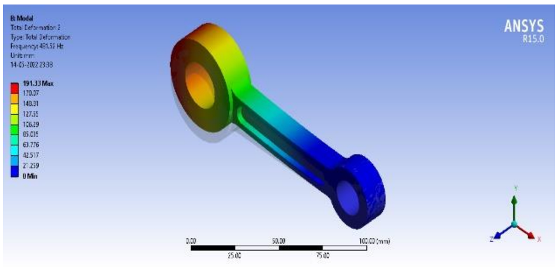
Table:-12

Modes	Frequency (Hz)	Total Deformation(mm)
1	302.51	196.38
2	481.52	191.33
3	995.43	269.06
4	2761.8	224.91
5	3592	195.23
6	5920.2	160.93

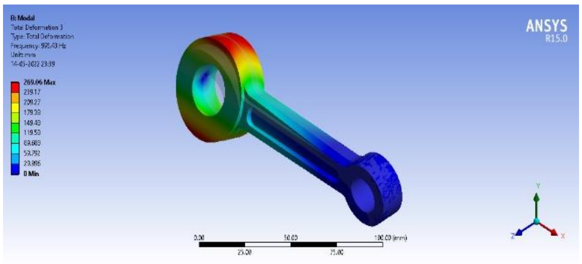
Mode-1:-Frequency(302.51)Hz



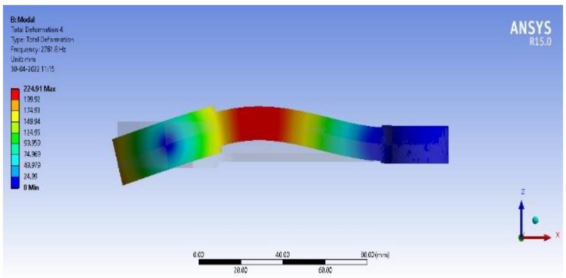
Mode-2:-Frequency(481.52)Hz



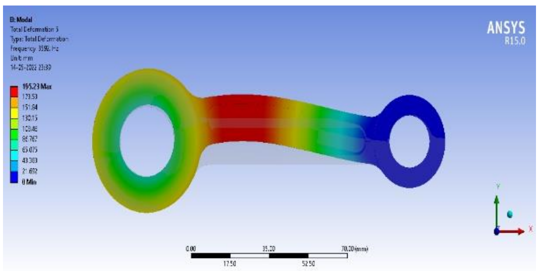
Mode-3:-Frequency(995.43)Hz



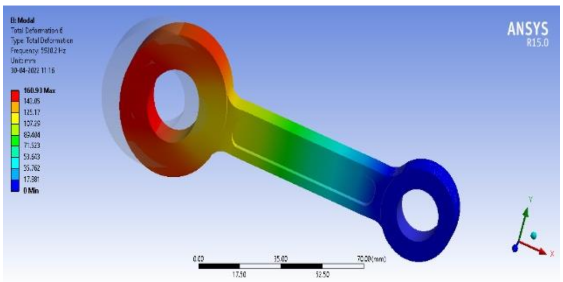
Mode-4:-Frequency(2761.8)Hz



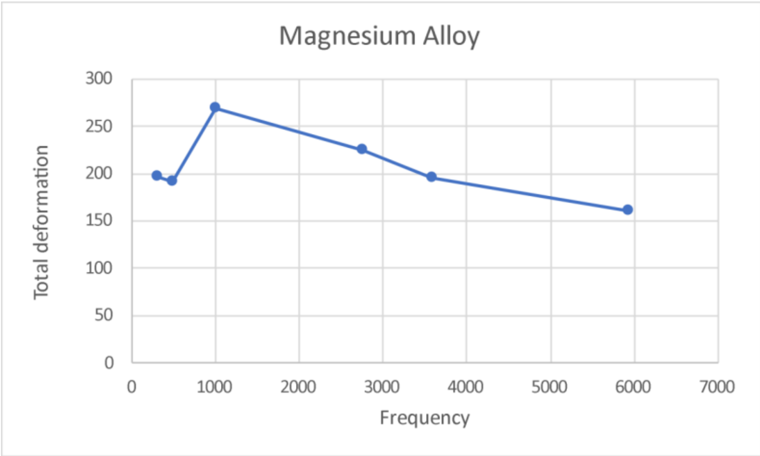
Mode-5:-Frequency(3592)Hz



Mode-6:-Frequency(5920.2)Hz



Graph (Frequency Vs Total Deformation)

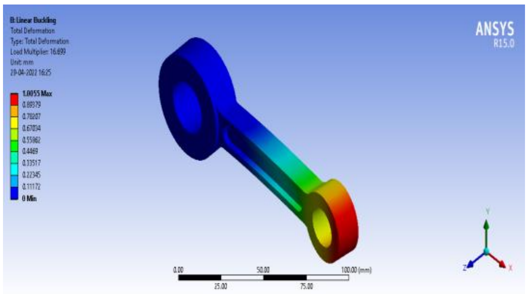


Line Graph 5

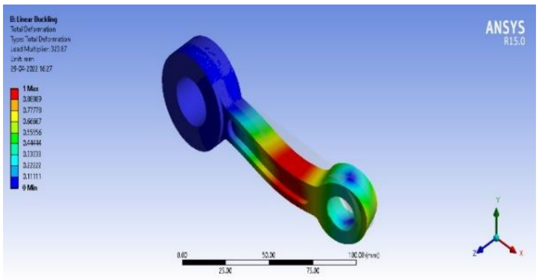
<u>Buckling Analysis</u>

<u>Aluminium Alloy:</u>

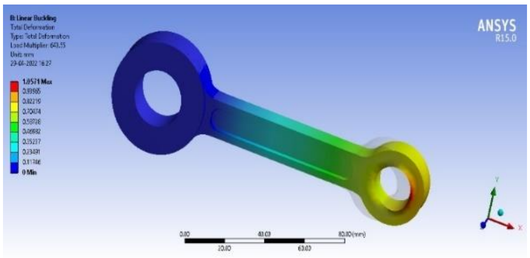
Mode-1:-Load Multiplier (16.699)



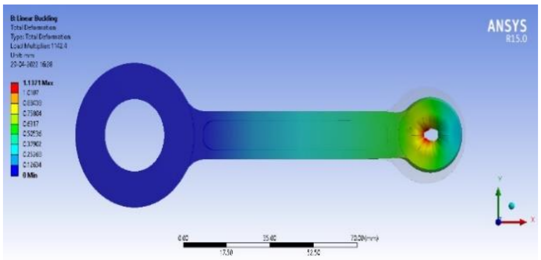
Mode-2:-Load Multiplier (323.87)



Mode-3:-Load Multiplier (643.55)

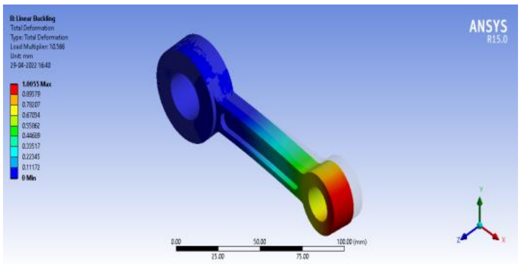


Mode-4:-Load Multiplier (1142.4)

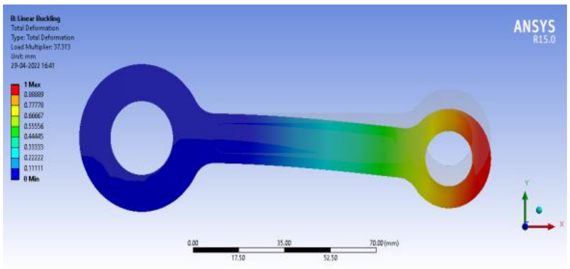


Magnesium Alloy:

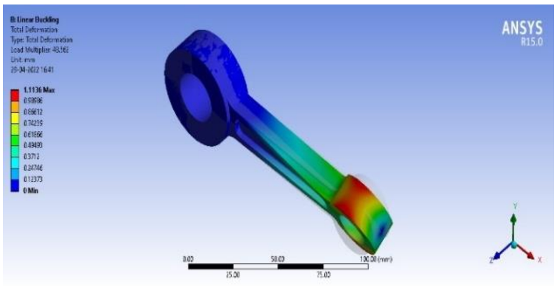
Mode-1:-Load Multiplier **(10.566)**



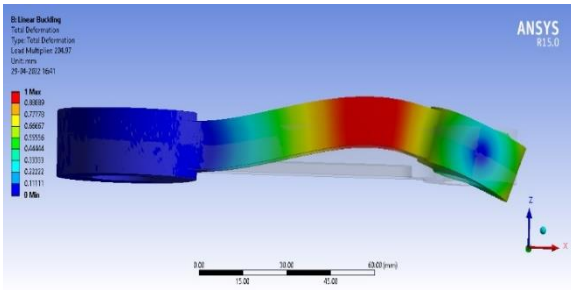
Mode-2:-Load Multiplier **(37.313)**



Mode-3:-Load Multiplier (48.562)



Mode-4:-Load Multiplier (204.97)



6.6 Interpretation of Buckling Analysis

From the Mode shapes and Load Multipliers obtained in the Buckling Analysis of the Connecting Rod, we can conclude as to which material to choose which will satisfy our criteria. The following is the summary

- The Aluminium Alloy has the highest Load Multiplier at Mode 1 and the rest of the modes when compared with Magnesium Alloy.
- Both Magnesium Alloy and Aluminium Alloy has the same Total Deformation Values when compared all four modes.

6.6 Interpretation of Modal Analysis

From the Mode shapes and Natural Frequencies obtained in the Modal Analysis of the Connecting Rod, we can conclude as to which material to choose which will satisfy our criteria. The following is the summary

- The Aluminium Alloy has the highest Natural Frequency at Mode 1 and the rest of the modes excluding medium carbon steels.
- The Magnesium Alloy has the lowest density compared to all other alloys in the analysis.
- The Aluminium Alloy AA 7075-T6 has the highest strength of all the alloys in comparison excluding medium carbon steels.
- The Natural Frequencies of Magnesium Alloy is very close to that of Aluminium.
- The Mode shapes of all the four materials resemble each other with very slight variations for all the six modes.
- The material with the highest Poisson ratio seems to have the highest resonant frequency.
- The Total Deformation is a maximum for Magnesium Alloy and minimum for Aluminium Alloy AA 7075-T6 for the resonant frequency.

CHAPTER-7

CONCLUSIONS

7 CONCLUSIONS: -

From the results obtained from the analyses we see that Aluminium Alloys has the highest natural frequency in the modal analysis and highest load multiplier values in buckling analysis. that is why Aluminium Alloy is commonly used for manufacturing Connecting rod. However, we notice that the natural frequencies of Magnesium Alloy are very close to that of Aluminium Alloys, which makes it safe to be used as a material for connecting rod. Magnesium Alloy is the lightest among all other alloys, which helps in reducing the weight of the rod. In addition to Magnesium Alloy can be easily manufactured by Die Casting method, which is cost-effective for high volume production than Sand casting.

However due to the fracturing nature of Magnesium Alloy it cannot be used as connecting rod for high load engines. Therefore, we conclude that Magnesium is best suited for low load ranging applications. The reduced weight not only increases the efficiency of the device but also makes it durable. These devices include Lawn Mowers, Generators, Compressors, Pumps etc.

The advantages of Magnesium Alloy are as follows:

- Lowest density of all metallic constructional materials.
- High specific strength.
- Good castability, suitable for high pressure die- casting.
- Good machinability.
- High thermal conductivity.
- High dimensional stability.
- Good electromagnetic shielding property.
- High damping characteristics. 100% recyclability.

But when Compared to Medium Carbon Steels Aluminium Alloys and Magnesium Alloy has more Total Deformation and Less Natural Frequencies because density of Carbon Steels are three times more than that of Aluminium Alloys and Magnesium Alloy.

So, strength wise medium carbon steels like 42MrCo4, AISI 1141 Steels as Rolled and Cold Drawn, C-90 are way more stronger than Aluminium Alloys AL 2024-T3, AA 6061-T6, AA 7075-T6 and Magnesium Alloy. These Aluminium And Magnesium Alloys can be used to manufacture Connecting Rods for the smaller engines.

Future Scope and Development

Further changes in the design of connecting rod can be made like selecting any other section other than the I-section. Further analysis is possible by choosing different materials for the connecting rod. Analysis of weight reduction and cost analysis can be done. Maximum stress concentration at the fillet of crank and piston end can be reduced by adding or removing material from the connecting rod. Chamfering of sharp boundaries of connecting rod also helps in reducing the stress level and increases strength of the connecting rod. Dynamic analysis of connecting rod can be done and other factors of failure can be considered. And also comparison can be done between medium carbon steels and aluminium alloys with increased weight of the connecting rod when analysis is being done with aluminium alloy because the density difference between these two materials is huge. So by increasing the aluminium metal weight in connecting rod a better results can be obtained.

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