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Structural and Thermal Analysis of Piston Including Piston Rings and Cylinder Liners by Using Finite Element Analysis

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Abstract – The cylinder liner and piston rings having frictional losses in the account of 20% of mechanical losses. The frictional losses can be reduced in the piston rings and cylinder liners, it causes higher efficiency and lower fuel consumption. The piston, piston rings and cylinder liners can also work at the higher temperatures and higher pressures and it reduces the frictional losses. In this project the design of piston, piston rings and cylinder liners are modelled in CATIA V5. The design of the engine parts is complex and efficiency is related to the type of material. The material is taken as ALUMINIUM-FLYASH-ALUMINA composite. Here the analysis is made in the ANSYS software where structural and thermal analysis of the piston can be determined.

Index Terms – Cylinder liner, CATIA V5, Aluminium-Flyash-Alumina.

1. INTRODUCTION

1.1. Introduction to IC Engines

Internal-combustion engine, one in which combustion of the fuel takes place in a confined space, producing expanding gases that are used directly to provide mechanical power. Such engines are classified as reciprocating or rotary, spark ignition or compression ignition, and two-stroke or four-stroke; the most familiar combination, used from automobiles to lawn mowers, is the reciprocating, spark-ignited, four-stroke gasoline engine. Other types of internal-combustion engines include the reaction engine (see jet propulsion, rocket), and the gas turbine.

Engines are rated by their maximum horse power, which is usually reached a little below the speed at which undue mechanical stresses are developed.

1.1.1. Evolution of the IC Engines

The first person to experiment with an internal-combustion engine was the Dutch physicist Christian Huygens, about 1680. But no effective gasoline-powered engine was developed until 1859, when the French engineer J. J. Etienne Lenoir built a double-acting, spark-ignition engine that could be operated continuously. In 1862 Alphonse Beau de Rochas, a French scientist patented but did not build a four-stroke engine; sixteen years later, when Nikolaus A. Otto built a successful four-stroke engine, it became known as the "Otto cycle." The first successful two-stroke engine was completed in the same year by Sir Dougald Clerk, in a form which (simplified somewhat by Joseph Day in 1891) remains in use today. George Brayton, an American engineer, had developed a two-stroke kerosene engine in 1873, but it was too large and too slow to be commercially successful.

In 1885 Gottlieb Daimler constructed what is generally recognized as the prototype of the modern gas engine: small and fast, with a vertical cylinder, it used gasoline injected through a carburetor. In 1889 Daimler introduced a four-stroke engine with mushroom-shaped valves and two cylinders arranged in a V, having a much higher power-to-weight ratio; with the exception of electric starting, which would not be introduced until 1924, most modern gasoline engines are descended from Daimler's engines.

1.1.2. Types of IC Engines

There are two main types of IC engines: spark ignition (SI) engines (petrol or gasoline engine) and compression ignition (CI) or diesel engine. Both these engines are further classified as 2-stroke and 4-stroke engine.

Internal Combustion Engines, more popularly known as IC engines, are the ones in which the combustion of fuel takes place inside the engine block itself. After combustion of fuel, much heat energy is generated; this is converted into mechanical energy.

There are two types of IC engines: rotary and reciprocating engines. In rotary engines, a rotor rotates inside the engine to produce power. In the case of the reciprocating engines, a piston reciprocates within a cylinder. The reciprocating motion of the piston is converted into the rotary motion of the vehicle's wheels. In automobiles, reciprocating engines are used. They are the most widely used type of engine.

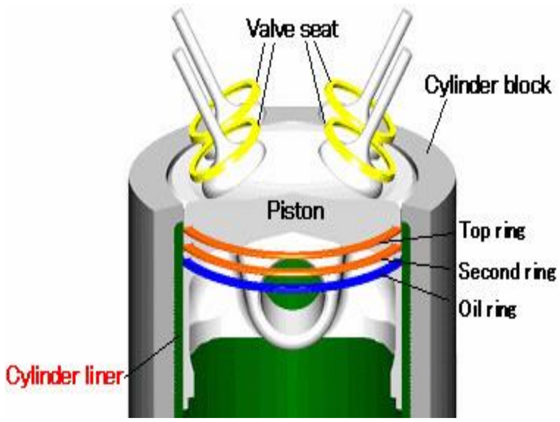


Fig 1.1 Typical View of Engine Parts

1.2. Introduction to Piston

The piston is a vital component of a cylindrical engine. It reciprocates inside the cylinder bore. The piston acts as a moveable end of the combustion chamber. The cylinder head is the stationary end of the combustion chamber. Piston head is the top surface (closest to the cylinder head) of the piston which is subjected to pressure fluctuation, thermal stresses and mechanical load during normal engine operation. By the forces of combustion, piston reciprocates inside the cylinder bore.

In order to increase the efficiency of operation and better functionality, the piston material should satisfy the following requirements:

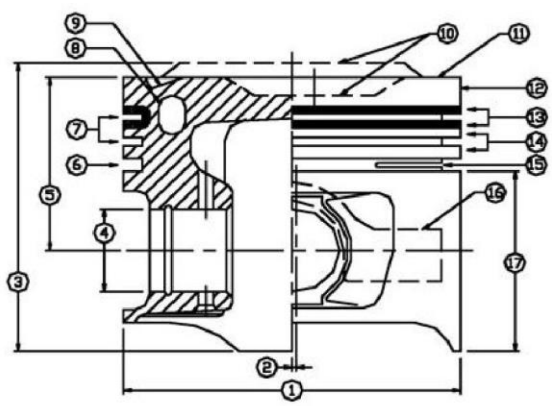


Fig 1.2 Piston

1.2.1. Types of Pistons

Two-stroke pistons

Are subject to strong mechanical and thermal loads due to the design principle of two-stroke engines. Special aluminum alloys are used so as to meet these requirements in the best possible way

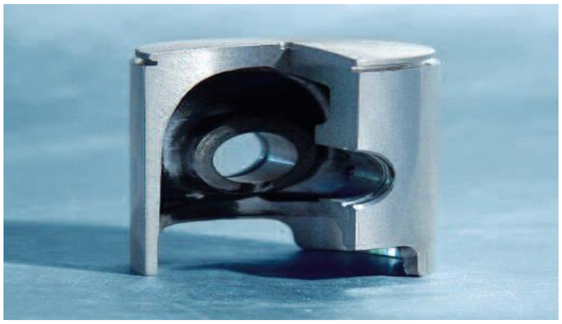


Fig1.5: Two Stroke Piston

1.3. Types of Piston Rings

Most automotive pistons have three rings: The top two while also controlling oil are primarily for compression sealing (compression rings); the lower ring is for controlling the supply of oil to the liner which lubricates the piston skirt and the compression rings (oil control rings). At least two piston rings are found on most piston and cylinder combination. Typical compression ring designs will have an essentially rectangular cross section or a keystone (right angled trapezoidal) cross section. The periphery will then have either a barrel profile (top compression rings) or a taper napier form (second compression rings or scraper rings). There are some taper faced top rings and on some old engines simple plain faced rings were used.

Fig1.9: Piston Rings & Oil Rings

1.4. Introduction to Cylinder Liners

Ever since its inception in 1960, the cylinder liner manufacturing activity at Cooper has grown from strength to strength. Today, the company is one of the top three cylinder liner manufacturers in the country, producing 2000 tons a month, and with expansion plans in the pipeline. Thanks to our extensive research in the area, the centrifugally cast Cylinder Liners are manufactured with a special alloy cast iron with selective elements.

1.4.1 Types of Cylinder Liners

Cylinder liners may be divided into two general classifications or types—dry or wet. The dry liner does not come in contact with the coolant. Instead, it fits closely against the wall of the cooling jacket in the cylinder block. With the wet liner, the coolant comes in direct contact with the liner. Wet liners may have a cooling water space between the engine block and liner, or they may have integral cooling passages. Liners with integral cooling passages are sometimes referred to as water-jacket liners.

Dry Liners

Dry liners have relatively thin walls compared with wet liners. Cross section of a dry liner can be seen in the right-hand view of figure. Note that the coolant circulates through passages in the block and does not come in contact with the liner.

Wet Liners

Liners of this type are constructed to permit lengthwise expansion and contraction. The walls of a wet liner must be strong enough to withstand the full working pressure of the combustion gases. In wet liners that do not have integral cooling passages, the water jacket is formed by the liner and a separate jacket which is a part of the block. A static seal must be provided at both the combustion and crankshaft ends of the cylinders to prevent the leakage of coolant into the oil pan sump, or combustion space. Generally, the seal at the combustion end of a liner consists of either a gasket under a flange or a machined fit. Rubber or neoprene rings generally form the seal at the crankshaft end.

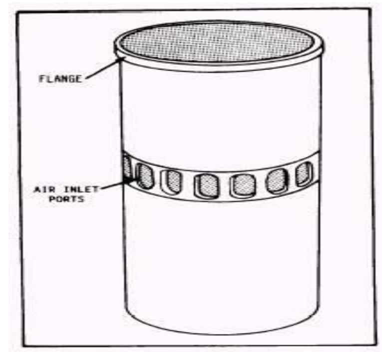


FIG 1.4.1: Dry cylinder liner

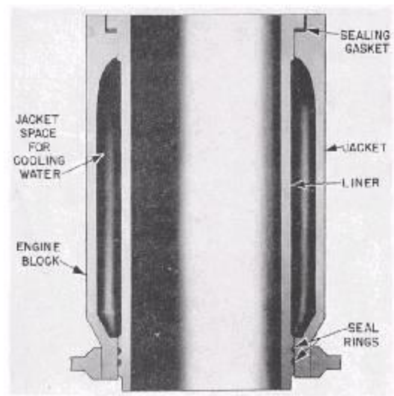


FIG1.4.2: wet cylinder liner

2. LITERATURE SURVEY

2.1. Introduction to Aluminium -Flyash-Alumina Composite**:**

Engine Piston is most complex part compared to other components in an automobile sector. Still lot of research works have been conducting on piston regarding material composition, geometry and manufacturing technique. The function of the internal combustion engine piston is to receive the energy from expanding gases after during combustion and transmit it to the crankshaft by means of connecting rod.

Piston expands appreciably when it gets heated during the operation so actual clearances need to be given otherwise it will lead to engine seize. And hence to avoid this case pistons are made up of cast aluminium alloy matrix with the combination of reinforcements in different weight percentage. For better results here I am replacing conventional piston material LM13-TF with new composite [Al6061 +Al_2O_3 + FLY ASH]. The addition of Fly ash and Alumina reinforcement particles to the Aluminium matrix improves the tensile strength, compressive strength and hardness behaviour. The reinforcement material is having more factor of safety compare to unreinforced alloy material because of more yield strength due to presence of the reinforcements in the matrix alloy.

2.2 Experimental Details

Stir Casting Technique

Fig:2.2 Stir Casting Technique

2.3 Sem Results

The figure shows that uniform distribution of reinforcement particles (Al2O3 and fly ash) in the matrix alloy and that result in improved of the mechanical properties. SEM micrograph at the higher magnification shows the particle-matrix interfaces. And lower magnification shows that the distributions of reinforcements like Al2O3 and fly ash particulate.

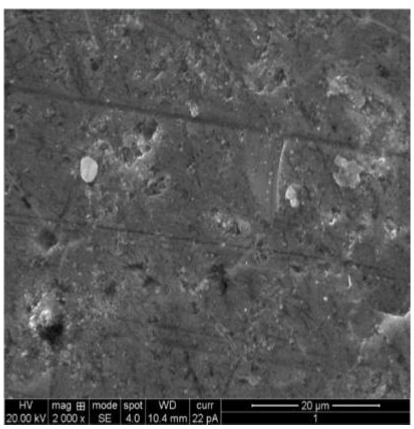


Fig: 3% Al2O3 + 15% Fly ash at 2000 X

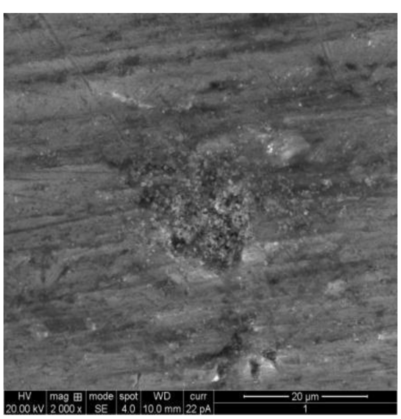


Fig2.3 : 6%Al2o3+15%fly ash at 2000x

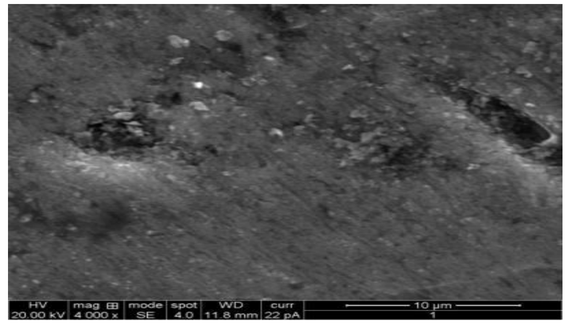
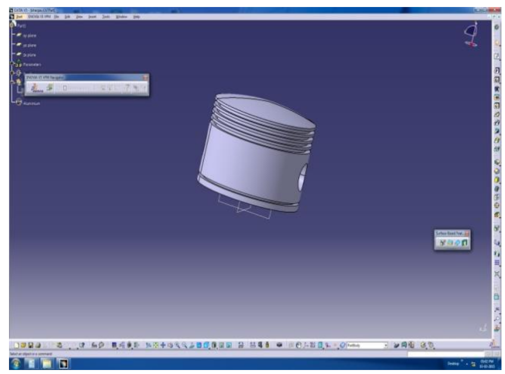


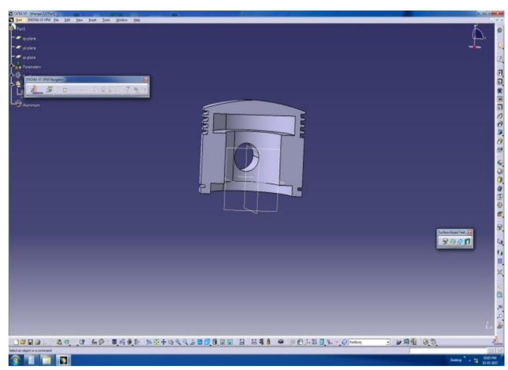
Fig: 9% Al2O3 + 15% Fly ash at 2000X

FIG 2.1: Uniform Distribution of Reinforcement

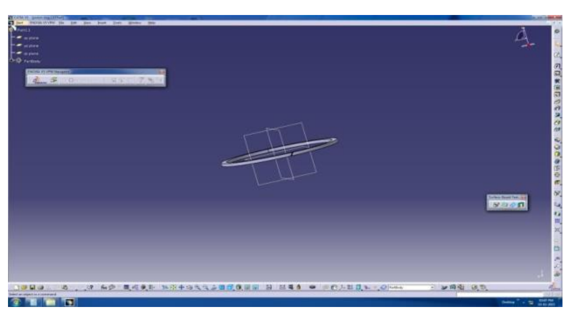
3. MODELLING OF ENGINE PARTS



3.1 Sectional View of Piston



3.2 Modelling of Piston Ring:



3.3 Modeling of Oil Ring

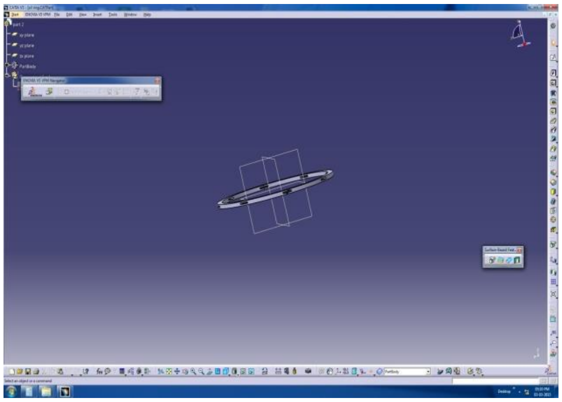


FIG3.3: OILRING

3.4 Modelling Of Cylinder Liner

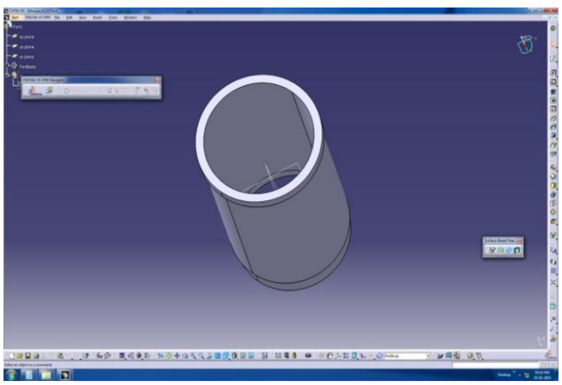


FIG 3.4 : CYLINDER LINER

3.5 Sectional View of Cylinder Liner

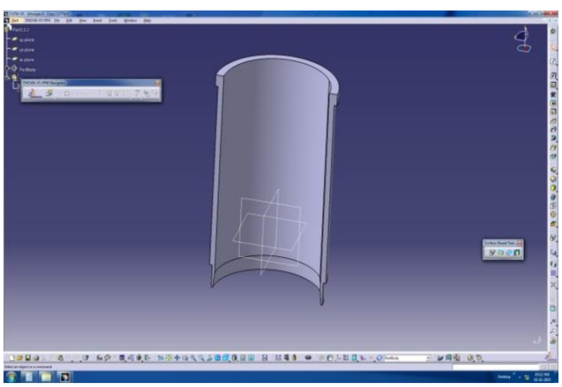


FIG3.5: SECTIONAL VIEW OF CYLINDER LINER

3.6 Assembly Model

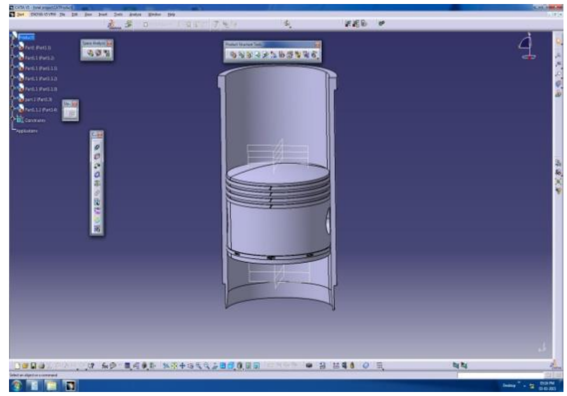
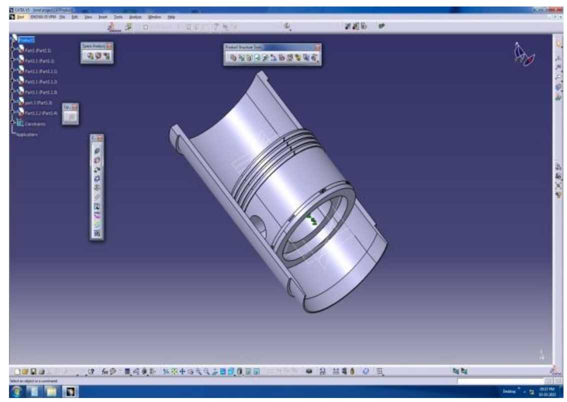


FIG3.6: ASSEMBLY PART



3.7 Sectional View Of Assebly Part

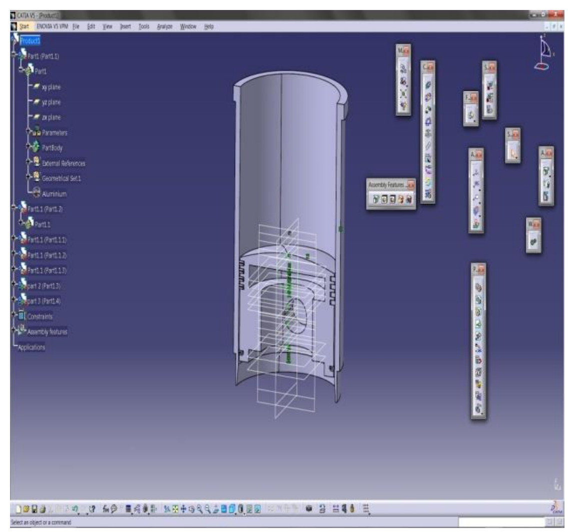


FIG3.7: SECTIONAL VIEW OF ASSEMBLY PART

3.8 Drafting Model Of Piston

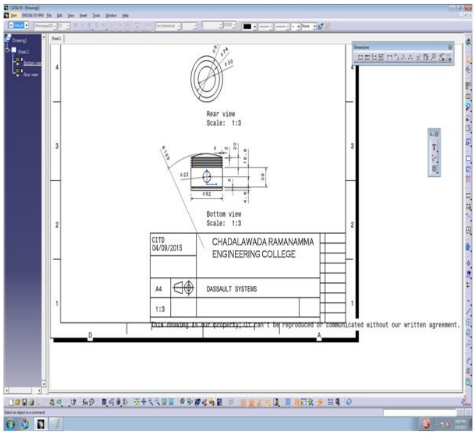
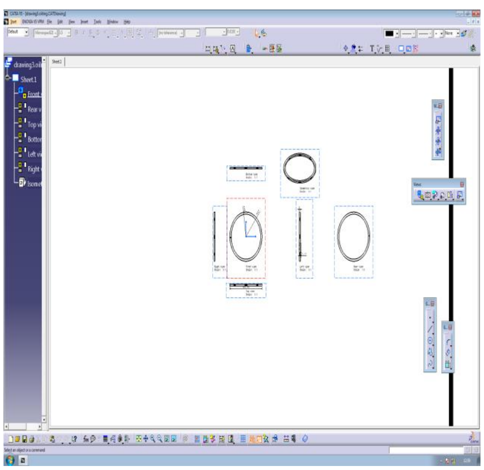
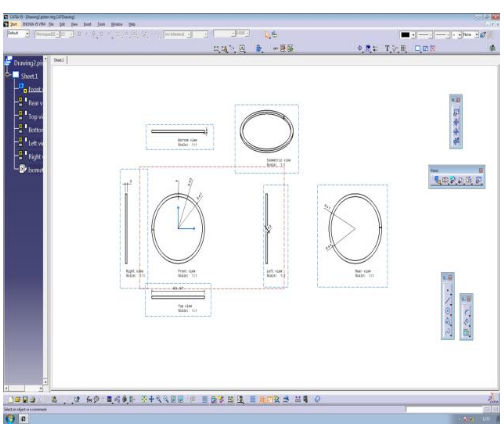


FIG 3.8: DRAFTING MODEL OF PISTON

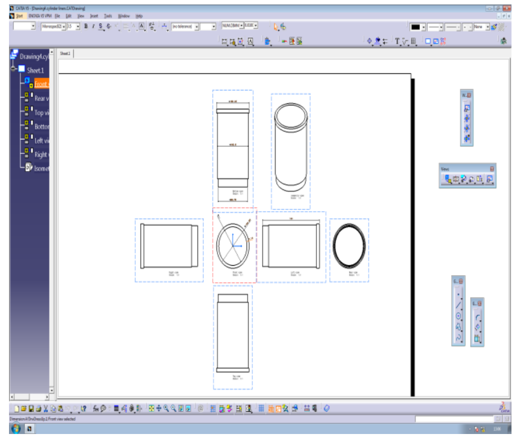
3.9 Drafting Model Of Oil Rings



3.9.1 Drafting Model Of Piston Rings



3.9.2 Drafting Model Of Cylinder Liner



4. ANALYSIS OF PISTON

The mesh generation is done in ANSYS MECHANICAL APDL 14.5 as per the standard. Static structural analysis is carried out in MECHANICAL APDL 14.5.

V.A. *Loading Condition*

In general the piston will be designed for high fatigue life cycles usually > 108 cycles life. In this project work we are considered the effect of pressure force and inertia force and it is assumed that side thrust force is negligible but in reality this may have some influence on stress and deformation of piston. Also the temperature effect is neglected and assumed that temperature is uniform. The pressure force and inertia force is applied on crown (i.e. top face) .

4.1. MESHING OF PISTON MODEL

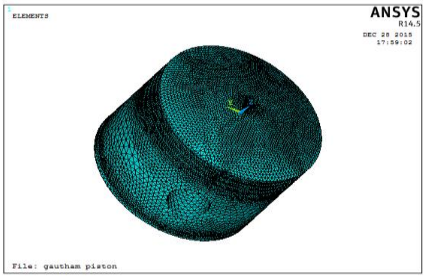
Material – ALUMINIUM

Pre-processing

Element type: Solid - brick 8 node 185

Material properties:

DENSITY	: 2.7gm/cc
ELASTIC MODULUS	: 79 Gpa
YIELD STRENGTH	: 95Mpa
ULTIMATE TENSILE STRENGTH	: 110Mpa
FATIGUE STRENGTH	: 96.5Mpa
POISSONS RATIO	: 0.33



Meshing - Mesh tool –Smart size – 4 – Mesh – Select solid

4.2 Structural Analysis Of Piston

Pre-processor – Loads – Displacement – On Areas – Plot controls – Numbering – On area no's – Ok – Plot – All DOF

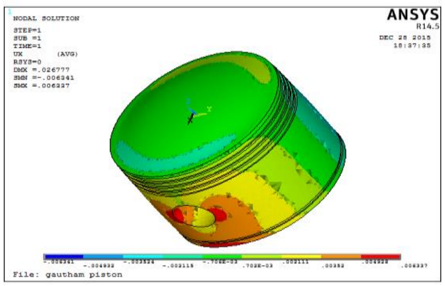


FIG 4.1: DISPLACEMENT IN X DIRECTION

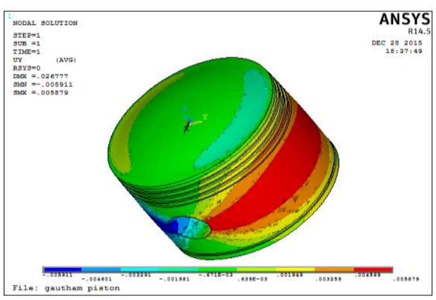


FIG 4.2: DISPLACEMENT IN Y DIRECTION

Pre-processor – Loads – Pressure – On Areas – ok

General post processor - Solution – Solve – Current LS

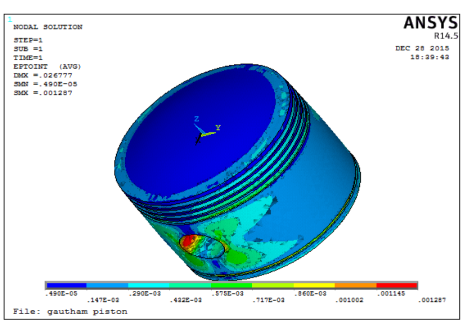


FIG 4.3: VONMISSILE STRESSES

4.3 Thermal Analysis Of Piston :

Meshing Of Piston Model

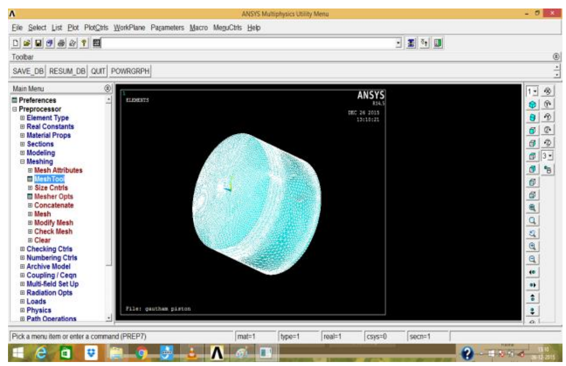
Material – Aluminium

Pre-processing

Element type: Solid - brick 8 node 185

Material Properties

Piston Head Temperature	:	300 ^{0}C
Thermal Conductivity	:	0.140 W/mm-k
Specific Heat	:	880 J/gm ^{0}C
Density	:	0.00000274 Kg/mm^3
Film Co-efficient Engine)	:	0.000323 mm (Inside the
Bulk Temperature	:	303^{0}C



Smart Size	:	1
Meshing	:	Triangular Elements

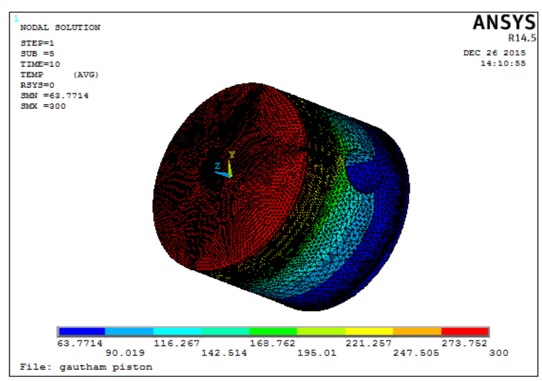


Fig 4.4: Thermal Distribution

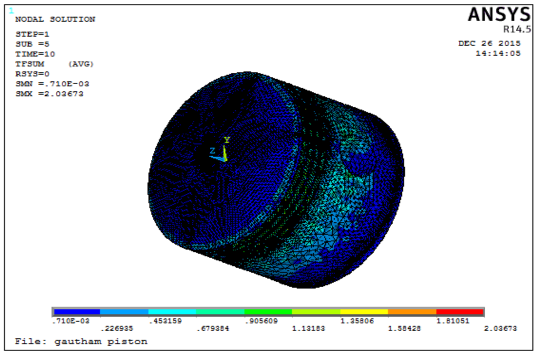


Fig4.5: Thermal Flux or Heat Flux

6.4. Analysis Of Piston:

For ALUMINIUM FLYASH ALUMINA COMPOSITE

MESHING OF PISTON MODEL

Material – ALUMINIUM FLYASH ALUMINA

Pre-processing

Element type: Solid - brick 8 node 185

Material Properties

Material properties:

DENSITY : 2.7gm/cc

ELASTIC MODULUS : 68.9Gpa

YIELD STRENGTH : 276Mpa

ULTIATE TENSILE STRENGTH : 330Mpa

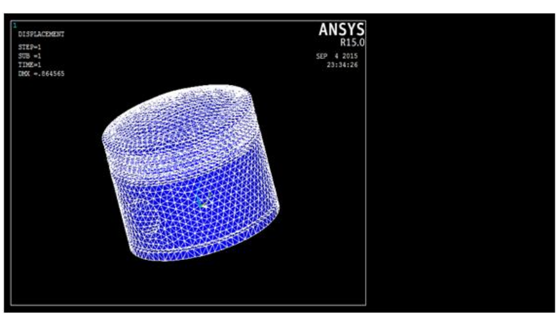
FATIGUE STRENGTH : 96.5Mpa

POISSONS RATIO : 0.33

PRESSURE ACTING ON THE TOP OF THE PISTON : 700bar

PRESSURE ACTING ON THE BOTTOM OF THE PISTON : 37.29

Meshing - Mesh tool –Smart size – 4 – Mesh – Select solid



MESHING OF PISTON

Here the 2D piston drawing is converted to 3D with a help of CATIA V5. The mesh generation is done in MECHANICAL APDL 14.5 as per the standard.

4.5 Structural Analysis Of Piston

Preprocessor – Loads – Displacement – On Areas – Plot controls – Numbering – On area no's – Ok – Plot – All DOF

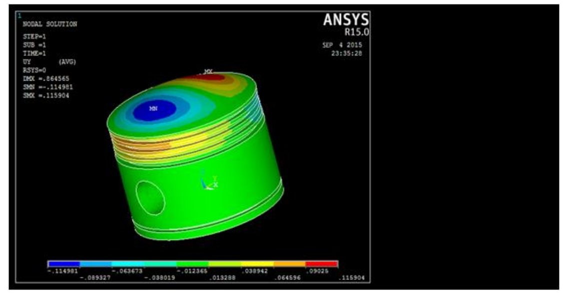


FIG4.6: DISPLACEMENT IN X DIRECTION

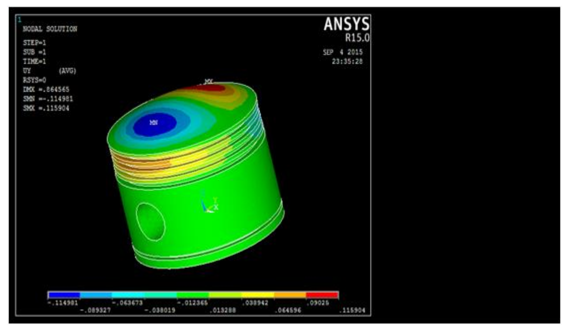


FIG6.7: DISPLACEMENT IN Y DIRECTION

Preprocessor – Loads – Pressure – On Areas – ok

General post processor - Solution – Solve – Current LS

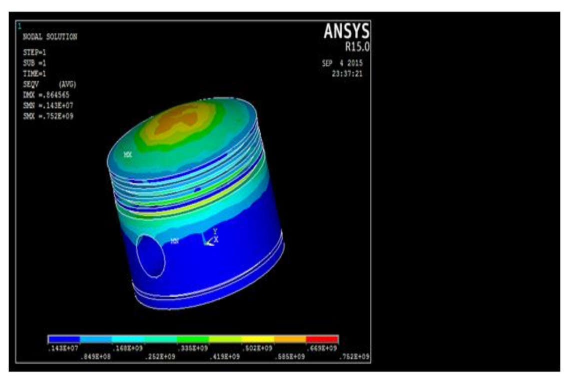


FIG4.8: VONMISSILE STRESS

4.6 Thermal Analysis Of Piston

Thermal Analysis Of Piston

Meshing Of Piston Model

Material – Aluminium Flyash Alumina Composite

Pre-processing

Element type: Solid - brick 8 node 185

Material Properties:

Piston Head Temperature	:	300 ^{0}C
Thermal Conductivity	:	0.104 W/mm-k
Specific Heat	:	780 J/gm ^{0}C
Density	:	0.00000201 Kg/mm^3
Film Co-efficient Engine)	:	0.000323 mm (Inside the
Bulk Temperature	:	303^{0}C

Preprocessor – Loads – Define Loads – Apply – Thermal – Temperature – On Lines – Selet line

Solution – Solve – Current LS

PISTON HEAD TEMPERATURE : 300^{0}C

The mesh generation is done in ANSYS MECHANICAL APDL 14.5 as per the standard. Static structural analysis is carried out in MECHANICAL APDL 14.5.

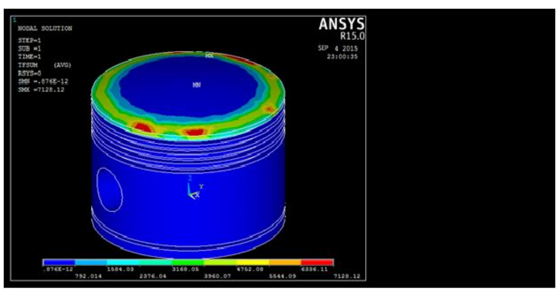


FIG 4.9: THERMAL FLUX

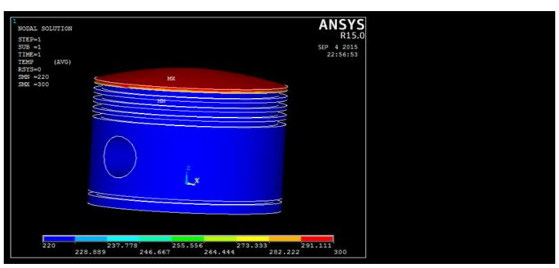


FIG 4.10: THERMAL DISTRUBUTION

5. RESULTS

Degrees of Freedom:

NODAL SOLUTION PER NODE

POST1 NODAL DEGREE OF FREEDOM LISTING

LOAD STEP= 1 SUBSTEP= 1

TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN THE GLOBAL COORDINATE SYSTEM

NODE	U SUM FOR AL	U SUM FOR COMPOSITE
1	0.18121E-02	0.14586
2	0.16298E-02	0.11786
3	0.30125E-02	0.85678E-01
4	0.26923E-02	0.52906E-01
5	0.16208E-02	0.24599E-01
6	0..18159E-02	0.24419E-01
7	0..14484E-02	0.25908E-01
8	0..21454E-02	0.27829E-01
9	0..20768E-02	0.27929E-01
10	0.37202E-02	0.28730E-01

The decrease in stress and increase in the displacement the fatigue resistance of the metal which in proper tends to improves the wear resistance and mechanical properities of the metal to protect the metal for increased life span and also induces proper combustion.

The thermal analysis of the piston shows the increase in the thermal distribution and also in thermal flux where the temperature is near to bulk temperature which increases the heat desipation contributes to efficient combustion.

Thermal distribution for Aluminium : (units in centigrade)

Minimum : 63.77

Maximum : 273.75

Thermal distribution for Aluminium flyash alumina composite : (units in centigrade)

Minimum : 228.88

Maximum : 300

This is mainly due to addition of flyash which has low density and less weight compared to Aluminium . Alumina which increases the mechanical properties such as wear resistance and re inforcement capability of metal

6. CONCLUSION

The Aluminium -fly ash -alumina composite is a metal to metal composite which increases the thermal efficiency and the displacement of the material when compared to other material. It improves the distribution of temperature and maintains the engine temperature with respect to the standard bulk temperature when compared to other. In this project, I was tested that the analysis is taken for the two materials are aluminium and aluminium fly ash alumina composite. The parameters are proved that the thermal distribution and thermal flux or Heat flux which involves in the better heat transfer rate which obtains the proper combustion of fuel and better deposition on the piston head when compared to the aluminium. So, here we can conclude that the aluminium fly ash alumina metal to metal composite has a better displacement, thermal distribution and thermal flux compared to aluminium.

Stress comparision from experimental set up (stir casting technique)

1) For Aluminium(Al 6061) : 314 mpa
2) For Aluminium – flyash –alumina composite :312 mpa (when Al 6061+3% Fly ash+15% alumina as a composite

Stress comparision from Analysis:

1) For Aluminium(Al 6061) : 0.01287 N /mm^2
2) For Aluminium – flyash –alumina composite : 0.752E+09 N/mm^2

Displacement from Analysis:

1) For Aluminium(Al 6061) : 0.02677 mm

2)For Aluminium – flyash –alumina composite : 0.864564 mm

And it is also further reduced as shown in the table above the stress values are reduced with increase in the percentage composition of Fly ash which has low density and less weight particle.

REFERENCES

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