International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 02 Issue: 09 | Dec-2015 www.irjet.net p-ISSN: 2395-0072

ANALYSIS OF ENGINE CYLINDER LINERS

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Abstract - ***A Cylinder Liner or also known as Sleeve is a cylindrical component that is placed in an engine block. It is one of the most important functional parts to make up the interior of an engine and it gives a wear protective surface for piston and piston rings.The barrel or bore in which an engine piston moves back and forth may be an integral part of the cylinder block, or it may be a separate liner. It is commonly used in gasoline engines, has the disadvantage of not being replaceable. When excessive wear occurs in a block of this type, the cylinder must be re-bored or honed. Reconditioning of this type cannot be repeated indefinitely and, in time, the entire block must be replaced. Another disadvantage is the inconvenience, especially in large engines, of having to remove the entire cylinder block from a ship in order to recondition the cylinders***

Key Words: *Cylinder Liner,Piston rings, wear resistance*

1. INTRODUCTION

A cylinder liner or also known as sleeve (Figure 1) is a cylindrical component that is placed in an engine block to form a cylinder. It is one of the most important functional parts to make up the interior of an engine and it gives a wear protective surface for piston and piston rings.

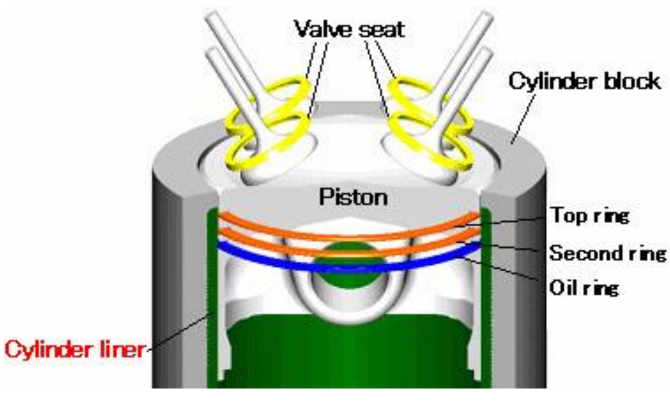


Figure 1. Cross-section of a cylinder in an internal combustion

A cylinder wall in an engine is under high temperature and high pressure, with the piston and piston rings sliding at high speeds. In particular, since longer service life is required of engines for trucks and buses, cast iron cylinders that have excellent wear-resistant properties are only used for cylinder parts

Also, with the recent trend of lighter engines, materials for engine blocks have been shifting from cast iron to aluminum alloys. However, as the sliding surface for the inner cylinder, the direct sliding motion of aluminum alloys has drawbacks in deformation during operation and wear-resistance. For that reason, cast iron cylinder liners are used in most cases.

What is the purpose of Liner:

The barrel or bore in which an engine piston moves back and forth may be an integral part of the cylinder block, or it may be a separate sleeve or liner. The first type, common in gasoline engines, has the disadvantage of not being replaceable. When excessive wear occurs in a block of this type, the cylinder must be rebored or honed.

Reconditioning of this type cannot be repeated indefinitely and, in time, the entire block must be replaced. Another disadvantage is the inconvenience, especially in large engines, of having to remove the entire cylinder block from aship in order to recondition the cylinders.

For these reasons, diesel engines are constructed with replaceable cylinder liners. The cylinder liners we will discuss are representative of those used in diesel engines

The material of a liner must withstand the extreme heat and pressure developed within the combustion space at the top of the cylinder and, at the same time, must permit the piston and its sealing rings to move with a minimum of friction. Close-grained cast iron is the material most commonly used for liner construction. (Steel, however, is sometimes used.)

Some liners are plated on the wearing surface with porous chromium, because chromium has greater wear-resistant qualities than other materials. Also the pores in the plating tend to hold the lubricating oil and aid in maintaining the lubrication oil film that is necessary for reduction of friction and wear

1. Formation of sliding surface:

The cylinder liner, serving as the inner wall of a cylinder, forms a sliding surface for the piston rings while retaining the lubricant within. The most important function of cylinder liners is the excellent characteristic as sliding surface and these four necessary points.

1.High anti-galling properties
2.Less wear on the cylinder liner itself
3.Less wear on the partner piston ring
4.Less consumption of lubricant

2. Heat transfer:

The cylinder liner receives combustion heat through the piston and piston rings and transmits the heat to the coolant. As shown in figure 2

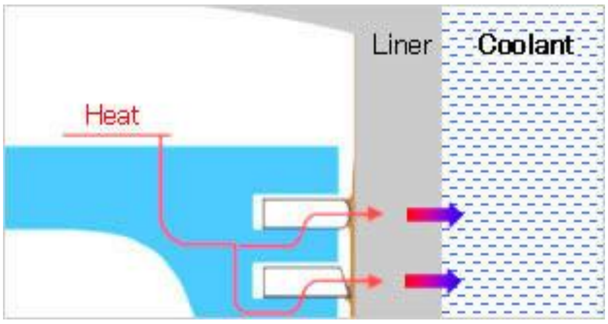


Figure 2. Heat transfer

3. Compression gas sealing:

The cylinder liner prevents the compressed gas and combustion gas from escaping outside. It is necessary that a cylinder liner which is hard to transform by high pressure and high temperature in the cylinder. As shown in figure 3

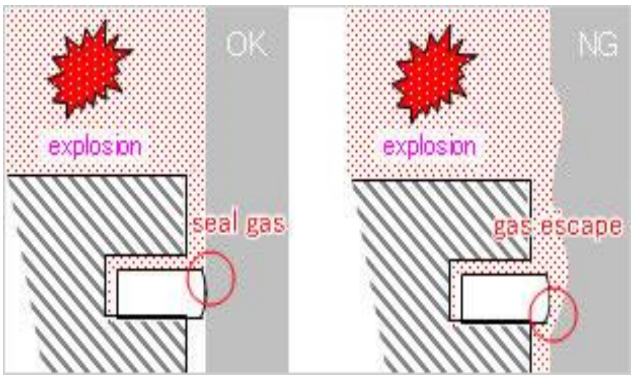


Figure3.Providing air tightness of cylinder liner

Types of Liners:

Cylinder liners may be divided into two general classifications or types, they are dry and wet liners. 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 (fig. 4). Note that the coolant circulates through passages in the block and does not come in contact with the liner

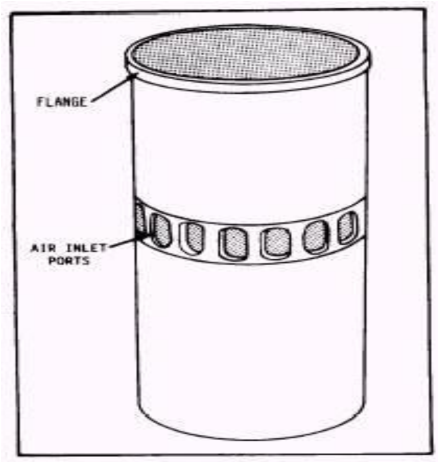


Figure 4—A dry cylinder liner (General Motors 71 series)

Wet Liners

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. (See fig. 3-11.) 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 of the liner. 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

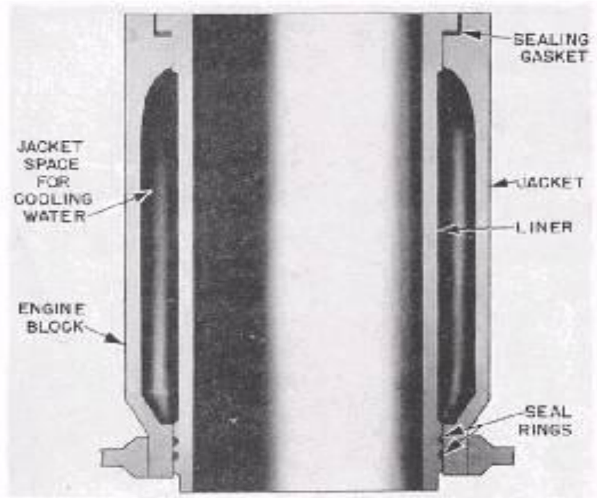


Figure 5—Cross section of a wet cylinder liner.

DESIGN OF LINER

The model we had use is FORD3600 ,it is an indian based automobile model.

The dimensions of this model are as follows:
Inner diameter: 105.50-105.70 mm
Outer diameter: 112.30-112.50 mm
Collar diameter: 113.70-113.90 mm
Total length : 211-212 mm
Collar width : 8-9 mm
By using this dimension we have drawn the solid 3D model in the ANSYS 15 workbench . The solid model is as follows:

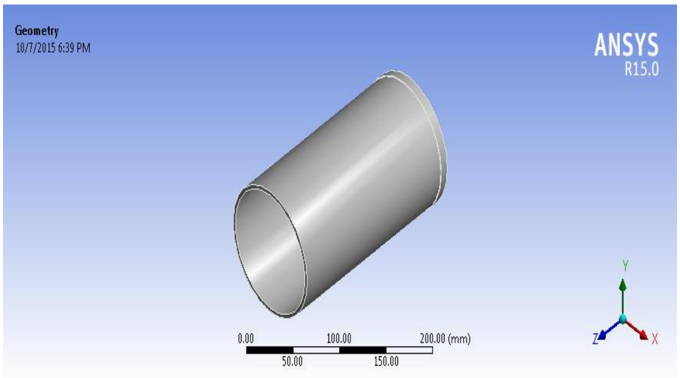


Figure : 6

After the geometry part is drawn , the solid model is used for meshing for further analysis .
By selecting all faces of the model the mesh is generated automatically .The mesh generated
is shown in figure

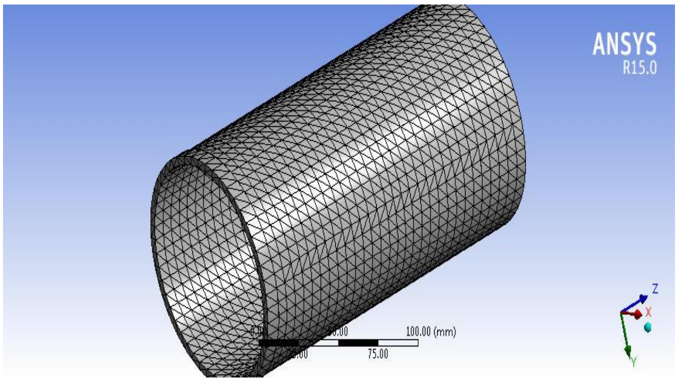
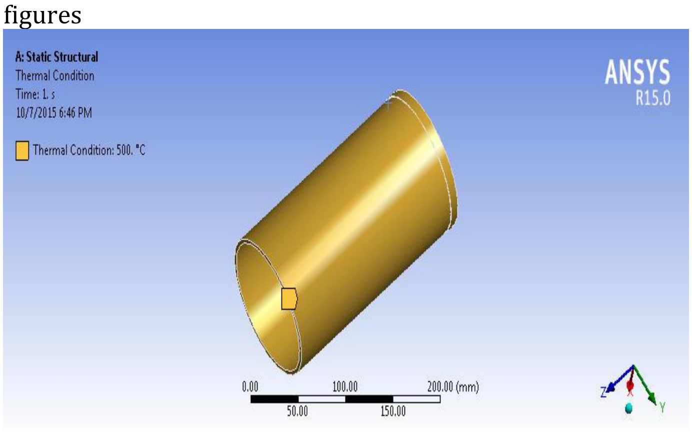
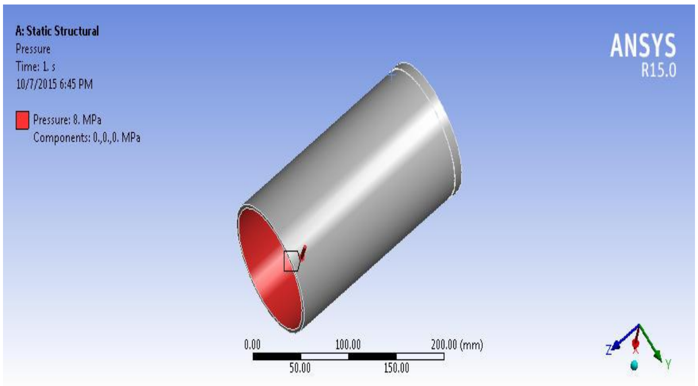


Figure : 7

After the meshing is over, the boundary conditions are given. The boundary conditions like forces, pressures, thermal conditions, supports, contacts for the model.
Here we had taken the pressure developed for the diesel engines i.e. about 5-8 Mpa.
The temperature developed in the engine cylinder is above 300 degree Celsius.
For a liner the outer surface is fixed , because it is to be fitted into the engine cylinder block so for this reason we had taken the outer surface of the liners are fixed.
All the boundary conditions are shown in the following figures





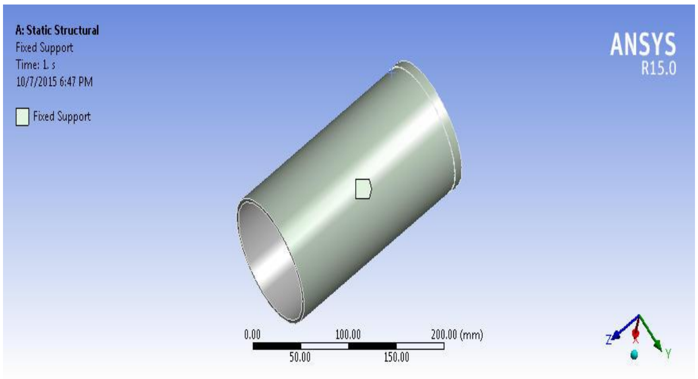


Figure: 8

Upto this the design part of the liner is completed. All the boundaries that are given for the model are , pressure that applied is 8 Mpa ,it is applied on the internal at internal surface of the liner . The thermal condition applied to the whole liner is 500 °C.

ANALYSIS OF LINER FOR DIFFERENT MATERIALS:

Normally the materials that are use for the liner manufacturing are grey cast iron, steel ,aluminum alloy. Here another material is also is used in our analysis i.e titanium alloy. Here the aim of our analysis is to find out best material for liner i.e. it should have a good durability and withstand the wear and corrosive nature

Grey cast iron:

Gray iron, or grey cast iron, is a type of cast iron that has a graphitic microstructure. It is named after the gray color of the fracture it forms, which is due to the presence of graphite. It is the most common cast iron and the most widely used cast material based on weight.

It is used for housings where the stiffness of the component is more important than its tensile strength, such as internal combustion engine cylinder blocks, pump housings, valve bodies, electrical boxes, and decorative castings. Grey cast iron's high thermal conductivity and specific heat capacity are often exploited to make cast iron cookware and disc brake rotors.

The composion of grey cast iron is C-2.7-4%,Mn-0.8%,Si-1.8-3%,S-max0.07%,P-max0.2%

The properties of the grey cast iron use for the analysis are,

Table :1-Physical properties

Density Kg/m^3	Poisson's Ratio	Young's Modulus Mpa	Ultimate Tensile Strength Mpa
7200	0.28	110000	240

Table :2- Thermal Properties

Thermal Conductivity W/m-k	Melting Point °C	Specific Heat J/gm°C
53.3	1090	0.490

Considering this properties the analysis is done , the deformation in grey cast iron liner is shown in the figure

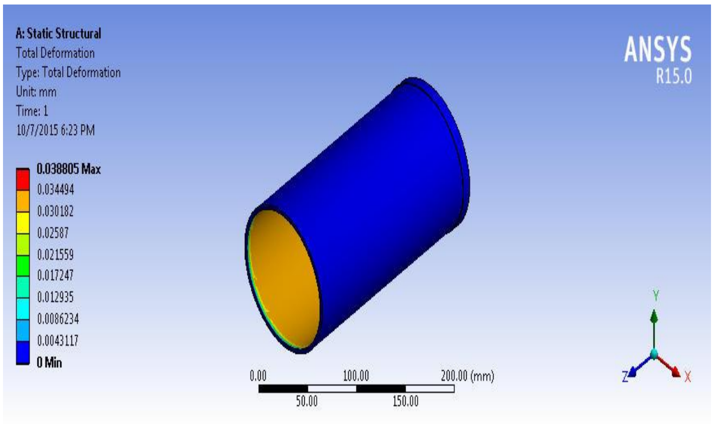


Figure 9: Deformation in liner

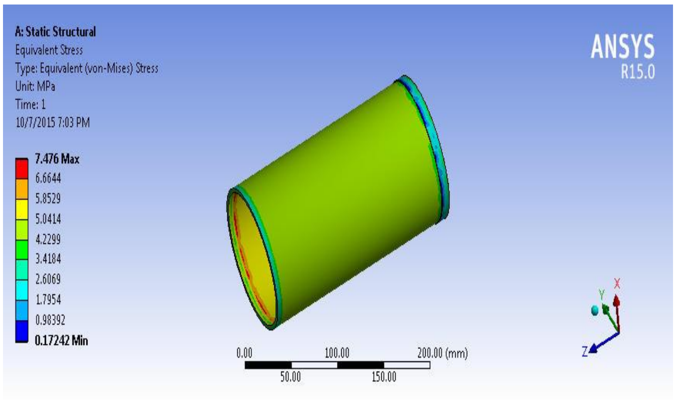


Figure 10: stress without temperature gradient

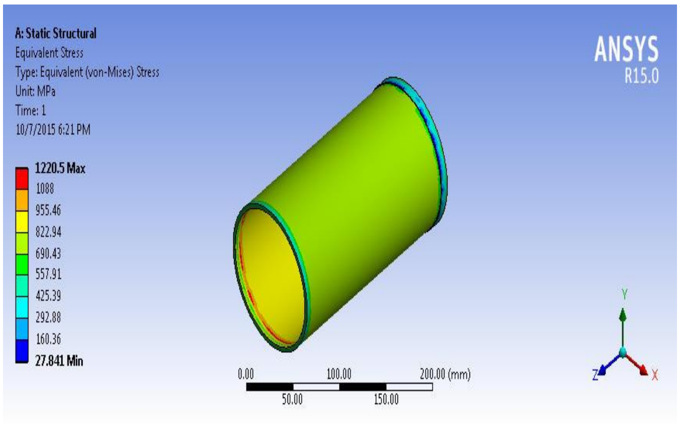


Figure11: stress with temperature gradient

Strain energy in the gray cast iron is

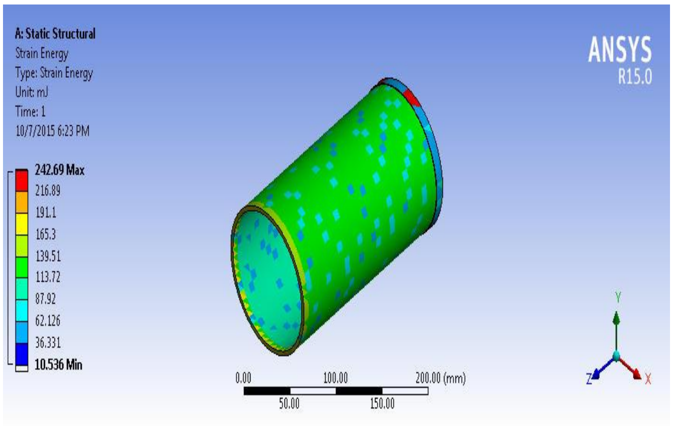


Figure 12: strain energy

The results for the grey cast iron are tabulated as follows

Table :3

Results	Minimum	Maximum	Units
Equivalent stress	27.841	1220.5	Mpa
Total Deformation	0	3.8805e-002	Mm
Strain Energy	10.536	242.69	mJ

Aluminium alloy:

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.its tensilestrength, 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 airplane and helicopters

The composition of aluminium is Al-95.8-98.6%, Cr-0.04-0.35, Cu-0.15-0.4%, Fe-max0.7, Mg-0.8-1.2%,Max0.15, i-0.4-0.8,Ti-max0.15,Zn-max0.25

The properties of the aluminium alloy used for analysis are

Table :4-Physical properties

Density Kg/m^3	Poisson's Ratio	Young's Modulus Mpa	Ultimate Tensile Strength Mpa
2770	0.33	71000	310

Table :5- Thermal Properties

Thermal Conductivity W/m-k	Melting Point °C	Specific Heat J/gm°C
167	582-652	0.896

Considering this properties the analysis is done , the deformation in aluminium alloy liner is shown in the figure

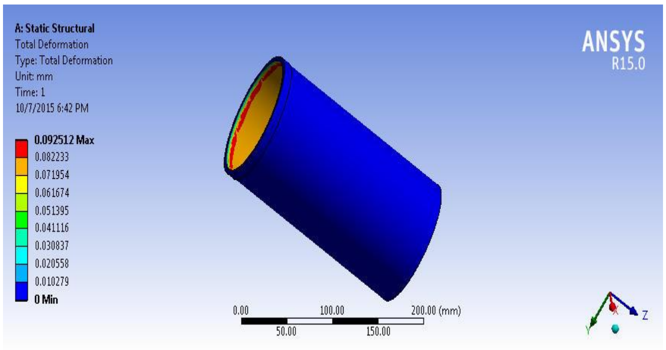


Figure :13-deformation

The stress developed in the liners with and without temperature gradient

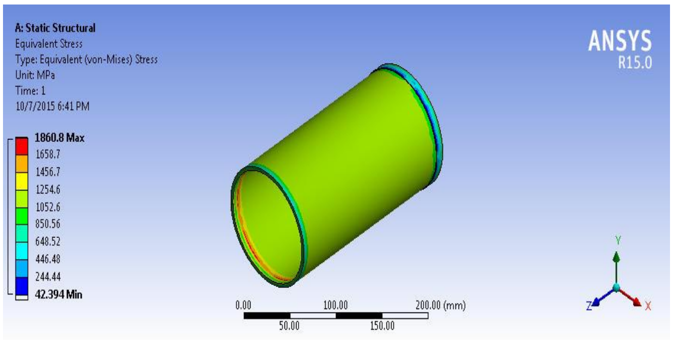


Figure :14-stress with temperature

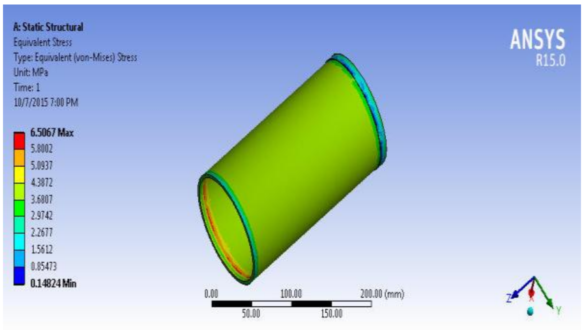


Figure :15-stress without temperature

strain energy in the aluminium alloy is shown in figure

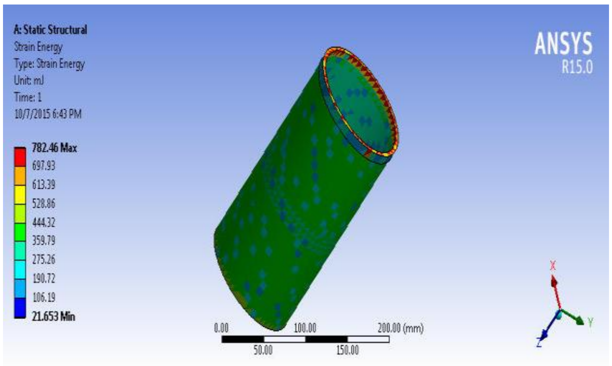


Figure:16-strain energy

Result are tabulated as below for aluminium alloy

Table :6

Results	Minimum	Maximum	Units
Equivalent stress	42.394	1860.8	Mpa
Total Deformation	0	9.2512e-002	Mm
Strain Energy	21.653	782.46	mJ

Stainless steel :

In metallurgy, **stainless steel**, also known as **inox steel** or **inox** from French "*inoxydable*", is a steel alloy with a minimum of 10.5% chromium content by mass.

Stainless steel does not readily corrode, rust or stain with water as ordinary steel does. However, it is not fully stain-proof in low-oxygen, high-salinity, or poor air-circulation environments.

There are different grades and surface finishes of stainless steel to suit the environment the alloy must endure. Stainless steel is used where both the properties of steel and corrosion resistance are required.

Stainless steel differs from carbon steel by the amount of chromium present. Unprotected carbon steel rusts readily when exposed to air and moisture. This iron oxide film (the rust) is active and accelerates corrosion by forming more iron oxide; and, because of the greater volume of the iron oxide, this tends to flake and fall away.

Stainless steels contain sufficient chromium to form a passive film of chromium oxide, which prevents further surface corrosion by blocking oxygen diffusion to the steel surface and blocks corrosion from spreading into the metal's internal structure. Due to the similar size of the steel and oxide ions, they bond very strongly and remain attached to the surface

The properties of stainles steel are

Table :7-Physical properties

Density Kg/m^3	Poisson's Ratio	Young's Modulus Mpa	Ultimate Tensile Strength Mpa
7750	0.31	193000	586

Table :8- Thermal Properties

Thermal Conductivity W/m-k	Melting Point °C	Specific Heat J/gm°C
26.1	1425-1510	0.460

Considering this properties the analysis is done , the deformation in stainless steel liner is shown in the figure

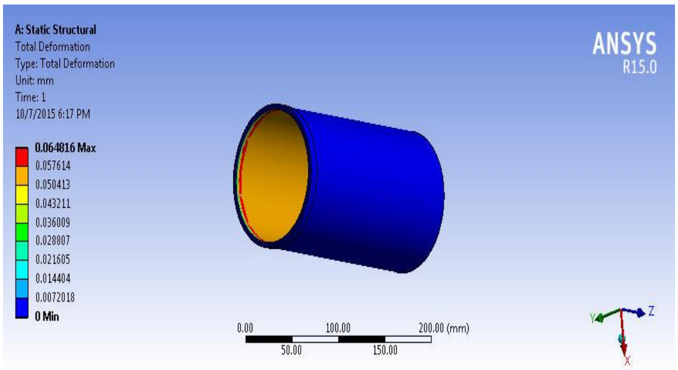


Figure :17 –deformation

The stress developed in the liner with and without temperature gradient are

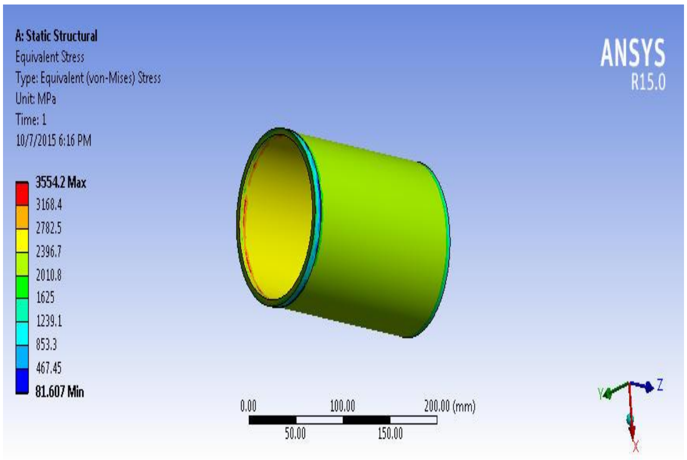


Figure :18 stress with temperature

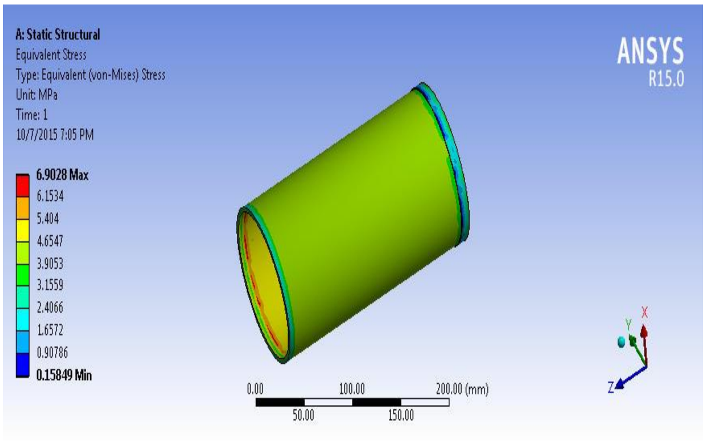


Figure :19 -stress without temperature

The strain energy in the liner is

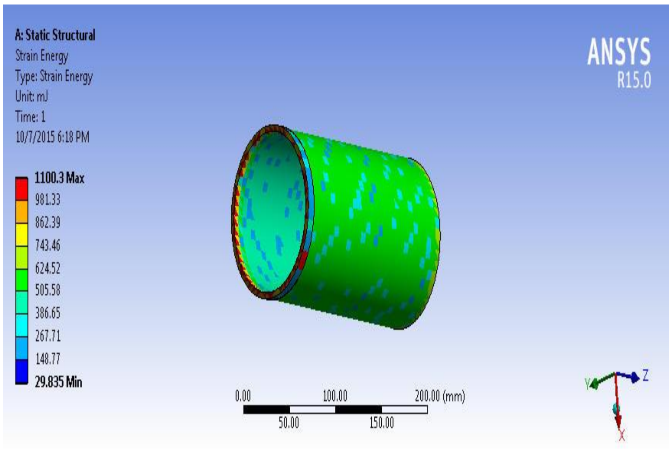


Figure:20 strain energy

Result are tabulated as below for Stainless steel

Table :9

Results	Minimum	Maximum	Units
Equivalent stress	81.607	3554.2	Mpa
Total Deformation	0	6.4816e-002	Mm
Strain Energy	29.835	1100.3	mJ

Titanium alloy :

Titanium alloys are metals that contain a mixture of titanium and other chemical elements. Such alloys have very high tensile strength and toughness (even at extreme temperatures). They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures.

However, the high cost of both raw materials and processing limit their use to military applications, aircraft, spacecraft, medical devices, highly stressed components such as connecting rods on expensive sports cars and some premium sports equipment and consumer electronics.

Although "commercially pure" titanium has acceptable mechanical properties and has been used for orthopedic and dental implants, for most applications titanium is alloyed with small amounts of aluminium and vanadium, typically 6% and 4% respectively, by weight.

This mixture has a solid solubility which varies dramatically with temperature, allowing it to undergo precipitation strengthening. This heat treatment process is carried out after the alloy has been worked into its final shape but before it is put to use, allowing much easier fabrication of a high-strength product.

The composition of the titanium alloy using in this analysis is Al-6%,Fe-max0.25, O-max0.2,Ti-90%,V-4%

The properties of the titanium alloy are

Table :10-Physical properties

Density Kg/m^3	Poisson's Ratio	Young's Modulus Mpa	Ultimate Tensile Strength Mpa
4620	0.36	96000	1070

Table :11- Thermal Properties

Thermal Conductivity W/m-k	Melting Point °C	Specific Heat J/gm°C
17.2	1604-1660	0.5263

Considering this properties the analysis is done , the deformation in titanium alloy liner is shown in the figure

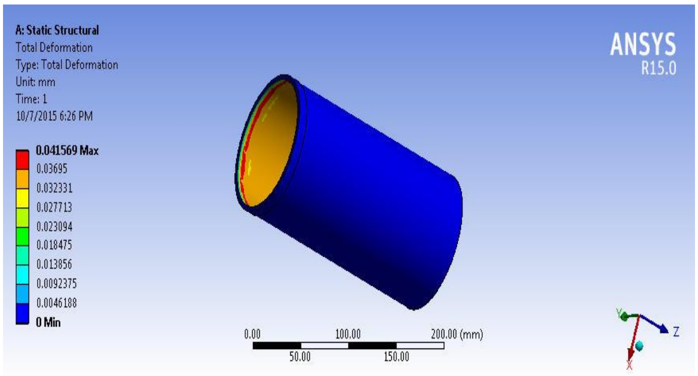


Figure:21-deformation

The stress developed in the liner with and without temperature gradient are

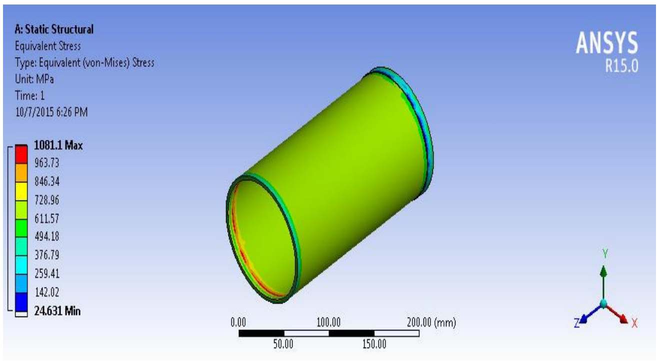


Figure :22 -stress with temperature

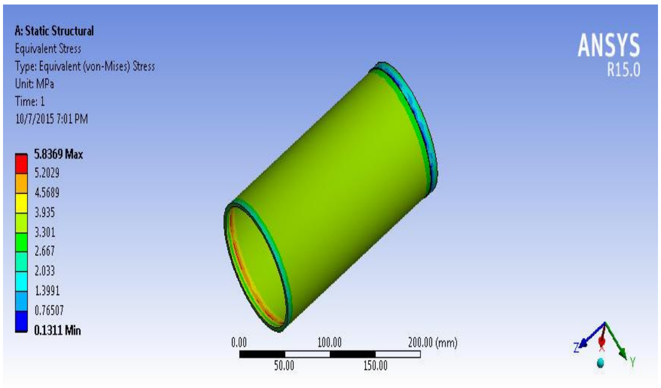


Figure :23-stress without temperature

The strain energy in the liner is

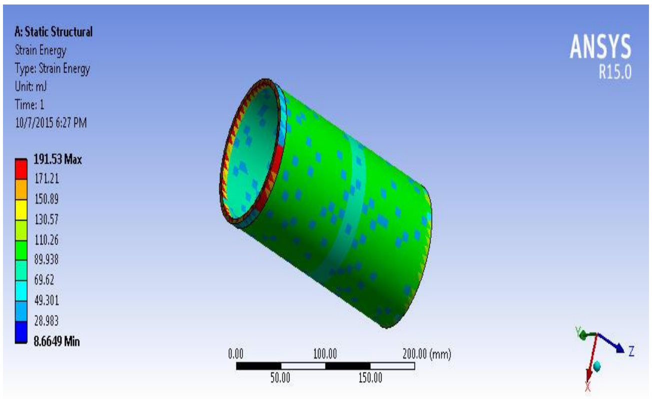


Figure :24-strain energy

Result are tabulated as below for Stainless steel

Table :12

Results	Minimum	Maximum	Units
Equivalent stress	24.631	1081.1	Mpa
Total Deformation	0	4.1569e-002	Mm
Strain Energy	8.666	191.53	mJ

Comparison of the results for material used in the analysis . By tabulating the values we got a brief view can be appears

Table :13

Results/materials	Equivalent stress Mpa	Total deformation mm	Strain energy MJ	Cost per kg rupees
Grey cast iron	1220.5	3.8805e-002	242.69	70
Aluminium alloy	1860.8	9.2512e-002	782.46	190
Stainless steel	3554.2	6.4816e-002	1100.3	280
Titanium alloy	1081.1	4.1569e-002	191.53	102

Actually ,the selection of material for the liners are based on the following terms, they are Young's Modulus, ultimate tensile strength, working temperature, thermal conductivity, melting point of the metal, wear resistance, hardness.

For the taken dimensions the factor safety is low for all the materials, titanium had good result than other materials at this high end condensations . In order to gain the good result the thickness of the liner should be increase to withstand the stress developed , this is to be done according to the specifications of engine cylinder and pistion. Normally the aluminium liners are use where the engine body is also made of aluminium. This is because it has high thermal coundtivity , so it will damage the engine block .The aluminium liners are preferable where the body is made of aluminium.The cast iron liners are mostly used onces. they have high hardness ,good thermal conductivity, and it is cheaper than other materials .when we use titanium alloy as liner mterial it can be effective

CONCLUSION :

After studying and analyzing cylinder liner using some materials following conclusions were drawn:

a) The cylinder liner made of titanium alloy is lighter than the existing cylinder liner.
b) ANSYS Equivalent stress (von mises) for the titanium alloy is slightly less than cast iron alloy which is currently used as cylinder liner.
c) Total deformation of titanium alloy is less than the current material (cast iron alloy).

Thus, although the cost of the titanium alloy is high, Titanium alloy is safe to use as cylinder liner.

IMPROVEMENT OF WEAR RESISTANCE IN LINERS

In today's automotive field cylinder liners plays a crucial role because they are integrated part of engine block .The cylinder liner is exposed to high temperatures while operating within the internal combustion engine. During the reciprocating motion of the piston, the piston will come in contact with the inner surface of the cylinder liner. Hence properties such as hardness and wear resistance of cylinder liner play a crucial role in determining efficient functioning of the cylinder liner.

NITRIDING :

Nitrding is a thermochemical process in which the surface of the ferrous metal is added with nitrogen inorder to improve wear resistance of the components. The diffusion process is based on the soloubility of nitrogen in iron. As nitriding is one of the important surface hardening technique this was being used in the manufacturing of aircraft, bearings, textile machinery and automotive components manufacturing such as valves, camshafts and piston rods etc.

WHY NITRIDING :

Nitriding process does not require a phase change i.e steel remains in the same ferrite phase during the complete process. While in the traditional process there will be a phase change from ferrite to austentite and austentite to martensite.As free cooling takes place in the nitriding process quenching is not required.Nitriding improves the fatigue life, provides anti-galling properties and high surface hardness. Nitriding process takes place comparitively at low temperatures when compared to other case hardening techniques and it is also cost effective.

RESULTS:

The nitriding process will cause a change in the microstructure of cylinder liner. The microstructures of the cylinder liner after nitriding process on both inner diameter and outer diameter of liner at top and bottom were shown below

The side indication marks in images indicate the white nitriding layer thickness

Figure :25 Nitrided Liner

Table :14

BEFORE NITRIDING	
Micro vickers hardness test	
Location	Observation in $HV_{50\ gm}$
Top OD	560.3
Top ID	516.7
Bottom OD	597.6
Bottom ID	576.6

Table :15

Nitriding layer thickness measurement by microscopic method	
Location	Microns
Top OD	12 – 13
Top ID	12 – 13
Bottom OD	10 – 11
Bottom ID	10 – 12

Although there is an increase in the thickness due to nitriding layer around 10-12 microns, the cylinder liner has been provided with extraordinary improvements. The hardness values of the cylinder liner were increased by about forty percent due to the nitriding process which results in very good improvement of wear resistance for liners. This resulted in a huge improvement in the life of cylinder liners and it was a success.

DISCUSSION :

In today's competitive automotive world cylinder liners provided with good hardness and wear resistance properties were best choosen to provide customer satisfaction. For the cylinder liner manufacturing industries to remain competitive in the present market situation implementation of nitriding process will be best suited in order to increase the life of the liners which they produce to satisfy customer requirements .It not only provides cylinder liners with good wear resistance but also improves the standards of customer satisfaction and also acts as an important heat treatment process compared to other traditional techniques.

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