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FEA and Thermal Analysis of Cylinder Liner of Marine Engine using Titanium Alloy (Grade 4)

Shubham Shah Kamlesh[1], Ruby Mishra[2], Nidhi Kumari[3] and Jay Kumar Gupta[4*]**

[1,3,4]KIIT University, Bhubaneswar
[2]SME ,KIIT University Bhubaneswar
E-mail: [1]shubham.prasad1@gmail.com, [2]rbm_mis@rediff.com, [3]nsinha165@gmail.com, [4]jay.gupta6588@gmail.com

Abstract—*A cylinder liner is a replaceable metal sleeve placed within the cylinder of an engine, forming a durable surface to withstand wear from the piston. Its key function is to form a sliding surface, transfer heat and seal compression gas. This paper illustrates designing and Analysis of cylinder liner of a marine engine by using titanium alloy (grade 4). Currently existing cylinder liner is manufactured by using Cast iron alloy. Finite element analysis of cylinder liner is done by considering the same material. The premium mixture of analytical parameters like Stress and strain, Deformation and Factor of safety for marine diesel engine cylinder liner are done in ANSYS software. Thermal analysis is also done using rate of conduction of above acknowledged material in the same software. Titanium alloy (grade 4) has more hardness and tensile strength so it can handle high pressures due to combustion of fuel. Due to low density it is lighter than cast iron alloy. It is already being used in condenser tubing to conduct heat, because of this utility titanium alloy (grade 4). is selected as a material to analyze. Titanium alloy (grade 4) is less vulnerable to wear due to its hardness and fatigue strength. As it is corrosion resistant it is apt for marine use. A parametric model of cylinder liner is modelled using CATIA V5 R21 software and to that model, analysis is carried out by using ANSYS 14.0 Software.*

Keywords*: marine engine, 4-stroke diesel engine cylinder liner, Titanium alloy (grade 4), corrosion resistant, FEA, Thermal analysis, CATIA V5 R21, ANSYS 14.0*

1. INTRODUCTION

A cylinder liner is a cylindrical part to be fitted into an engine block to form a cylinder. It is one of the most important functional parts to make up the interior of an engine. 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. (5) High Thermal conductivity.(6) Hard to transform by high pressure and high temperature.

The cylinder liner receives combustion heat through the piston and piston rings and transmits the heat to the coolant. 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 to be fitted in the cylinder. 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 for Marine engines, 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. if the cylinder liner is to be used When designing and choosing material for cylinder liner of a marine engine anti corrosion property is very important. Particularly in wet liners cooled directly by water corrosion rate is high due to oxidization of metals. this adds to the maintenance cost. Thermal properties of a material are also very important in selection of material for cylinder liner.

2. LITRATURE SURVEY

To reduce the above mentioned failures and drawbacks of cylinder liner various researches are done by changing materials, doing analysis of various designs, Fatigue analysis etc. This brief literature survey reviews some of these aspects.

For losses due to Friction between cylinder liner and piston ring [1] Bedajangam S. K et al in their research "Friction Losses between Piston Ring-Liner Assembly of Internal Combustion Engine: A Review" showed that the losses due to friction is as high as 20% of total mechanical loss. [2] M.F. Ahmad Fakaruddin et al in their research paper "Material Selection For Wet Cylinder Liner" compared 5 materials by which cylinder liner can be possibly made. The materials that were selected for analyzing were Carbon Steel, Cast PH

Stainless Steel, Cast Nickel-Chromium Alloy, Low Alloy Steel and Wrought PH Stainless Steel. Cast Nickel-Chromium Alloy proved to be the best among these 5 materials due to its high Young's Modulus, high fracture toughness, good tensile strength and durability, it can also work at high temperatures easily.

3. OBJECTIVE

The main objective of this paper is to give an alternative material for cylinder liner with more life cycles, which will be much lighter in weight, which will not corrode easily and last longer even when in contact with marine water and has better thermal conductivity.

Thus Titanium alloy (Grade 4) was selected. This material is rigid, has better fatigue strength, less density, better corrosion resistance capacity than other materials and good thermal conductivity which remains constant even at high temperatures.

Hence, cylinder liner is designed and Analyzed using CATIA V5 R21 software and ANSYS V14 software respectively to find the stresses, strain, deformation and heat flux of the cylinder liner.

4. ENGINE SPECIFICATIONS

4.1 Yanmar type 8SY-STP

Configuration : 4-stroke, vertical, water cooled diesel engine

Maximum output at crankshaft: 662 kW (900 hp) / 2300rpm

Continuous rating output at crankshaft: 503 kW (655 hp) / 2100 rpm

Displacement: 15.6 L (952 cu in)

Bore x stroke: 127 mm x 154 mm (5.0 in x 6.1 in)

Cylinders: V8-type 90°

Combustion system: Direct injection

5. CALCULATION

Table 1: Nomenclature & Data Used

Name	symbol	Value
Bore	D	127 mm
Length of stroke	L	154 mm
Displacement of one cylinder	V_c	1950 cc
Max. Power	P_b	662 Kw
Gas pressure	P	12.3 MPa
No. of bolts.	N	4
Tensile stress of bolt material	σ_{tb}	80 - 100 MPa
Tensile stress of Cylinder head material	σ_{th}	550 MPa

6. FORMULAS USED

i) Pressure Calculation for 15.6 lit V8-type marine Engine

Density of diesel fuel = 860 kg/m^3

= 860× 10^{-9} kg/mm^3

Temperature = 15 °C

Mass = Density × Volume

From Gas Equation,

PV = Mtr R

= Rx/Mw

P = 12.3 MPa

ii) Design of cylinder liner

Thickness of cylinder liner

T_l = 0.03D ~ 0.035D

Thickness of flange

T_f = 1.2 T_l ~ 1.4 T_l

Thickness of water Jacket

T_w = 0.08D + 6.5

Thickness of cylinder head

$$T_h = 0.5D\sqrt{\frac{P}{\sigma th}}$$

Nominal dia of bolt d

= 1.2 × core dia of bolt

Length of cylinder

= L + Length of piston + Bottom clearance

Table 2: Specifications of cylinder liner

Sr. No.	Parameters	Value
1	Inner dia of cylinder liner (Bore dia) D	127 mm
2	Length of cylinder L	300 mm
3	Thickness of cylinder liner T_l	4 mm
4	Thickness of flange T_f	6 mm
5	Thickness of water Jacket T_w	16.66 mm
6	Thickness of cylinder head T_h	10 mm
7	Nominal dia of bolt d	21 mm

7. MODELING AND ANALYSIS

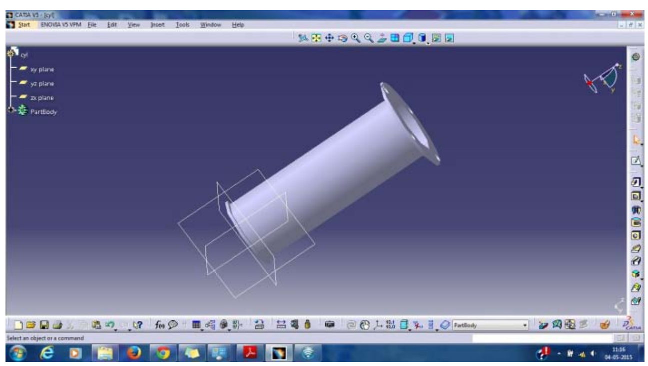

Fig. 1: Design of Cylinder Liner

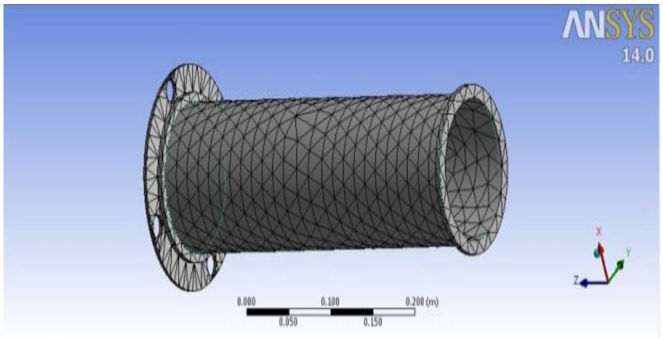

Fig. 2: Mesh model

Mechanical Analysis

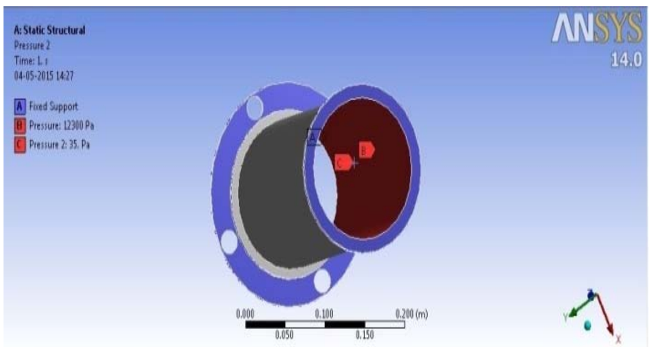

Fig. 3: Loads Applied

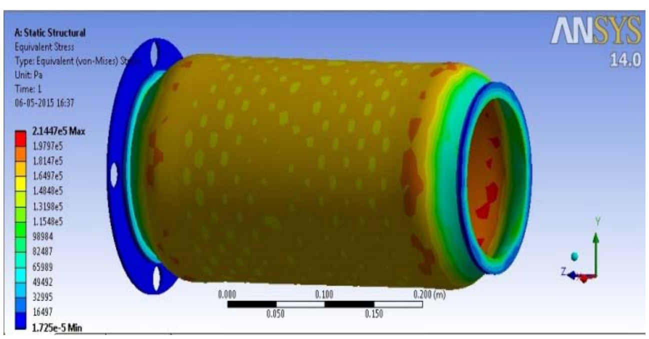

Fig. 4: Equivalent stress (Von-Mises)

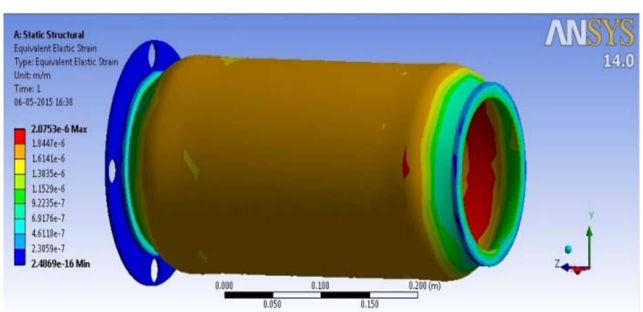

Fig. 5: Equivalent Elastic Strain(Von-Mises)

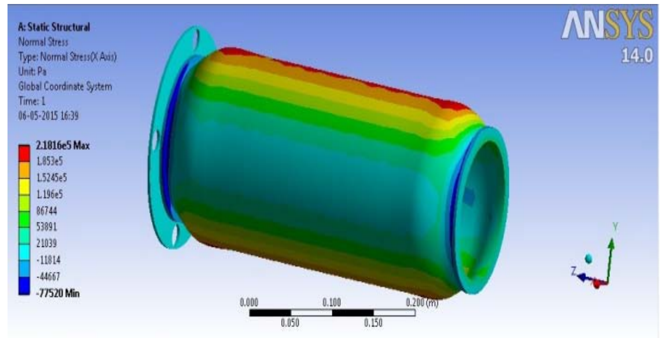

Fig. 6: Normal stress (X axis)

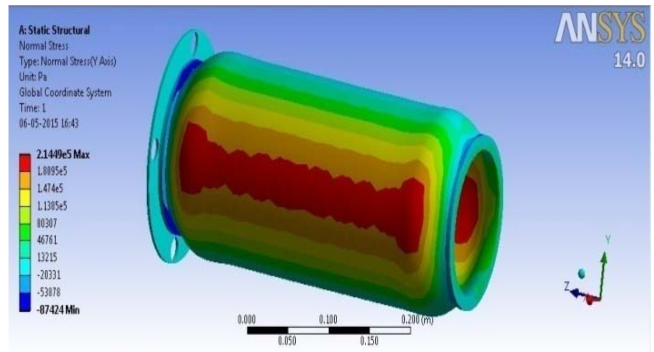

Fig. 7: Normal stress (Y axis)

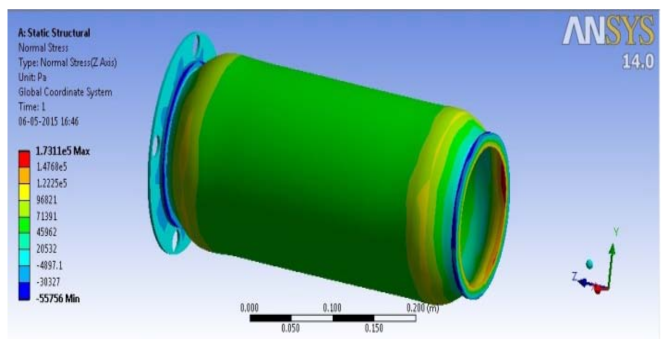

Fig. 8: Normal stress (Z axis)

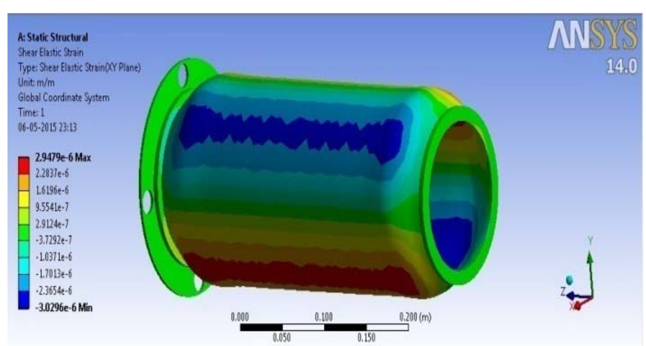

Fig. 9: Shear elastic strain (XY Plane)

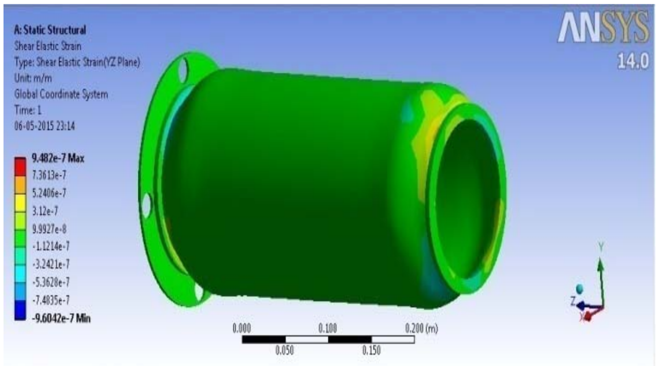

Fig. 10: Shear elastic strain (YZ Plane)

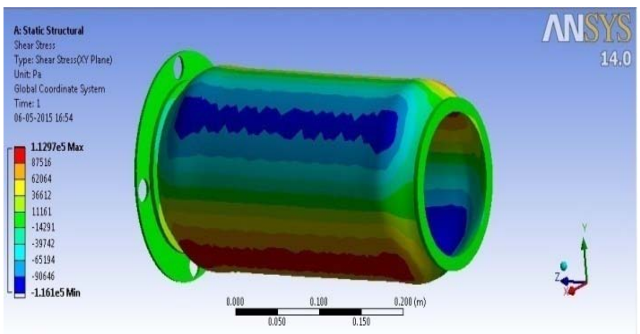

Fig. 11: Shear stress (XY Plane)

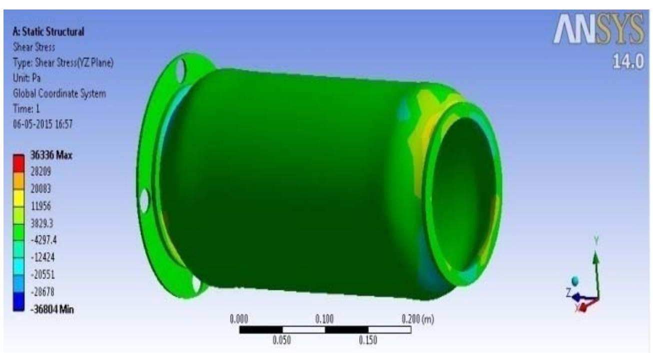

Fig. 12: Shear stress (YZ Plane)

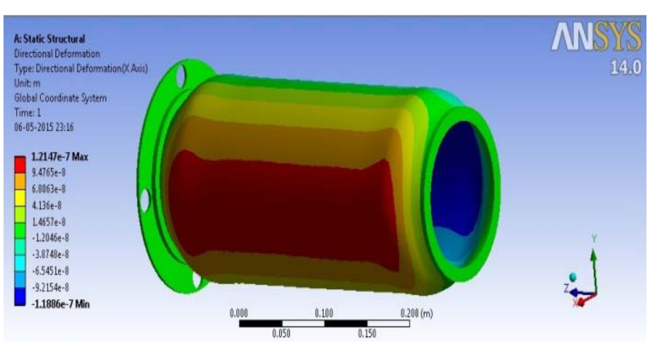

Fig. 13: Deformation (X Axis)

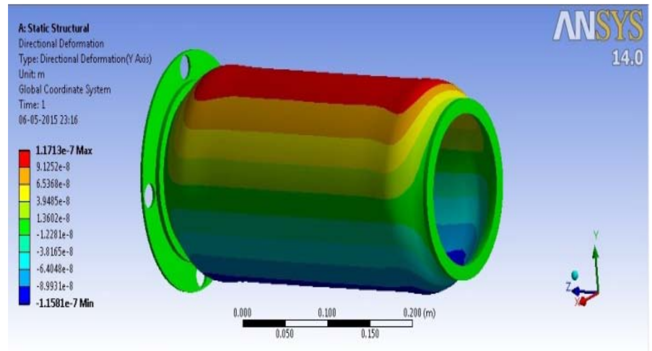

Fig. 14: Deformation (Y Axis)

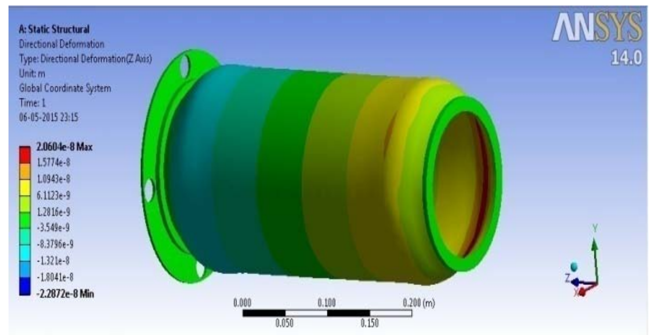

Fig. 15: Deformation (Z Axis)

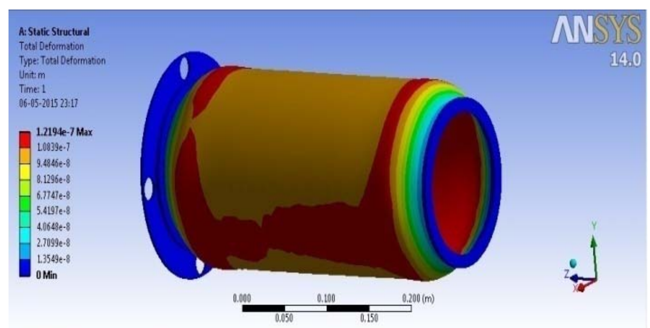

Fig. 16: Total Deformation

Thermal Analysis

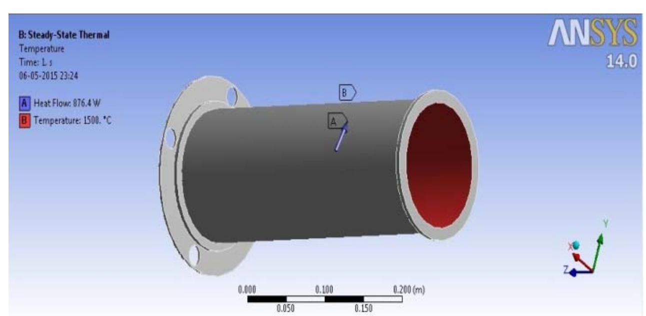

Fig. 17: Heat Flow & Temperature

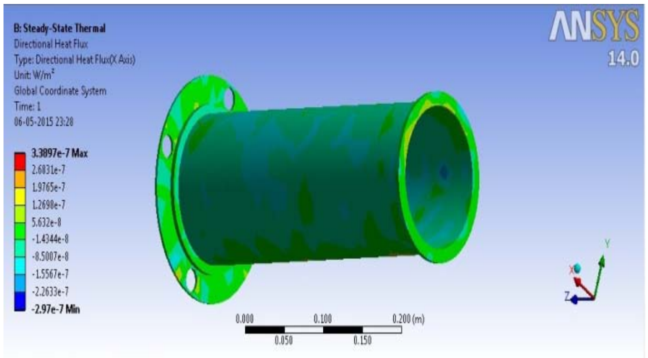

Fig. 18: Heat Flux (X axis)

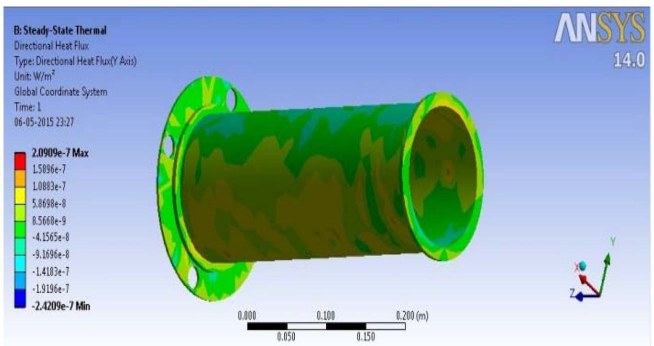

Fig. 19: Heat Flux (Y axis)

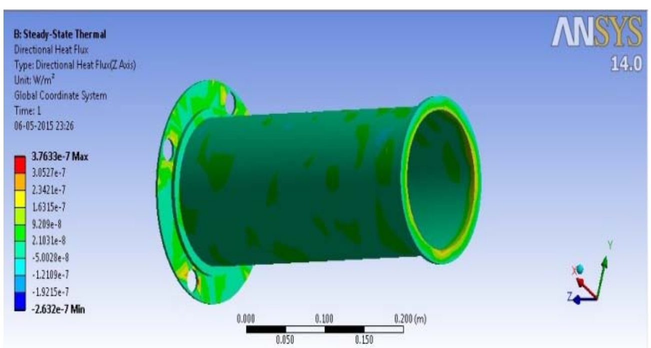

Fig. 20: Heat Flux (Z axis)

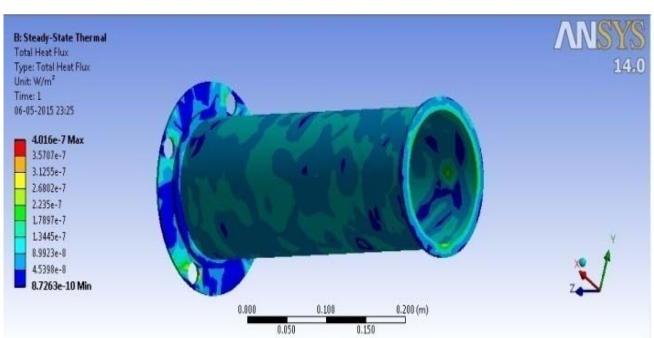

Fig. 21: Total Heat Flux

8. DISCUSSION

Fig. 1. Cylinder liner was designed as per calculations in CATIA V5 R21 software.

Fig. 2. To do a finite element analysis Meshing of model of cylinder liner was done in ANSYS V14.0 Software.

Fig. 3. Fixed supports were selected and Gas Pressure and sliding contact pressure was applied to the cylinder liner

Fig. 4&5. Von- mises stress and strains were Analyzed taking in consideration the above pressures and loads.

Fig. 6, 7 & 8. Normal stress in different directions affecting the cylinder liner were analyzed.

Fig. 9 & 10. Shear elastic strain in different planes affecting the cylinder liner were analyzed.

Fig. 11 & 12. Shear stress in different planes affecting the cylinder liner were analyzed.

Fig. 13, 14 & 15. Deformation in each direction were analyzed.

Fig. 16 Total deformation caused by pressures were analyzed and max deformation was found using ANSYS V14.0 software.

Fig. 18, 19, 20 & 21. Heat flux in each direction were analyzed which gave an idea about the distribution of heat in the material. in the end total heat flux was found through analysis.

9. RESULTS

Table 3: Stress, Strain & Deformations of Titanium alloy (Grade 4)

Sr. No.	Parameters	Min. Value	Max. Value
1	Equivalent stress (von-mises)	1.725×e^-5 Pa	2.1447× e^5 Pa
2	Equivalent elastic strain (von-mises)	2.4869×e^-16	2.0753× e^-6
3	Normal stress (X axis)	-77520 Pa	2.1816× e^5 Pa
4	Normal stress (Y axis)	-87424 Pa	2.1449× e^5 Pa
5	Normal stress (Z axis)	-55756 Pa	1.7311× e^5 Pa
6	Shear elastic strain (XY plane)	-3.0296×e^-6	2.9479× e^-6
7	Shear elastic strain (YZ plane)	-9.6042× e^-7	9.4820× e^-7
8	Shear stress (XY plane)	-1.161× e^5 Pa	1.1297× e^5 Pa
9	Shear stress (YZ plane)	-36804 Pa	36336 Pa
10	Deformation (X axis)	-1.1886×e^-7 m	1.2147× e^-7 m

11	Deformation (Y axis)	-1.1581×e^-7 m	1.1713× e^-7 m
12	Deformation (Z axis)	-2.2872×e^-8 m	2.0604× e^-8 m
13	Total Deformation	0 m	1.2194× e^-7 m
14	Heat Flux (X axis)	-2.97× e^-7 W/m2	3.3897× e^-7 W/m2
15	Heat Flux (Y axis)	-2.4209×e^-7 W/m2	2.0909× e^-7 W/m2
16	Heat Flux (Z axis)	-2.632× e^-7 W/m2	3.7633× e^-7 W/m2
17	Total Heat Flux	8.7263× e^-10 W/m2	4.0160× e^-7 W/m2

Table 4: Mechanical &Thermal properties of Titanium Alloy (Grade 4)

Parameters	Value
Density	4510 kg m^-3
Young's Modulus	1.05e+011 Pa
Poisson's Ratio	0.37
Bulk Modulus	1.3462e+011 Pa
Shear Modulus	3.8321e+010 Pa
Compressive Yield strength	6.e+008 Pa
Tensile Ultimate Strength	5.5e+008 Pa
Tensile Yield strength	5.5e+008 Pa
Specific Heat	526.3 J kg^-1 C^-1
Thermal Conductivity	17.2 W m^-1 C^-1

10. CONCLUSION

After studying and analyzing cylinder liner using Titanium alloy (grade 4) following conclusions were drawn:

a) The cylinder liner made of titanium alloy (grade 4) is lighter than the existing cylinder liner.

b) ANSYS Equivalent stress (von mises) for the titanium alloy (grade 4) 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 there are designing requirements to optimize and reduce vibration increase thermal conductivity in cylinder liner of a marine engine, Titanium alloy (grade 4) is safe to use as cylinder liner.

11. ACKNOWLEDGEMENTS

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