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DESIGN AND ANALYSIS OF DRY CYLINDER LINER WITH FEA

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Abstract - *A Cylinder liner is a cylindrical part to be fitted in to an engine block to form a cylindrical space in which the piston reciprocates very smoothly. It is one of the most important functional parts to make up the interior of an engine. Generally cylinder liners are made of cast- iron, Cast steel, Nickel cast-iron, Nickel chrome cast-iron. The aim of this project is to design and analyze a dry cylinder liner for Hino-X- diesel engines. A Hino-X- engine cylinder dry liner used in one of Ashok Leyland model manufactured by "Kusalava Industries" Vijayawada, is taken as the standard dimensions for the present dry liner. The amount of heat generated, heat transfer rate of the component, temperature produced inside the cylinder are calculated using ANSYS analysis package. Various surface coatings like ceramic, aluminum alloys and Nickel chrome alloy steel are used to study the heat flux, thermal stresses, thermal displacement, thermal gradient, nodal temperatures of the cylinder liner. Modeling is done in Pro/Engineer and analysis is done by coupled field analysis in ANSYS.After comparing the results, the best coated cylinder dry liner for this type of diesel engine is suggested.*

Key Words: **ANSYS, aluminum alloys, ceramic, cylinder liner, Pro-Engineer, surface coatings, Nickel chrome alloy steel.**

1. INTRODUCTION

The internal combustion engine is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber. In an internal combustion engine the expansion of the high-temperature and -pressure gases produced by combustion applies direct force to some component of the engine, such as pistons, turbine blades, or a nozzle. This force moves the component over a distance, generating useful mechanical energy [1].

The term internal combustion engine usually refers to an engine in which combustion is intermittent, such as the more familiar four-stroke and two-stroke piston engines, along with variants, such as the Wankel rotary engine. A second class of internal combustion engines use continuous combustion: gas turbines, jet engines and most rocket engines, each of which are internal combustion engines on the same principle as previously described [2-5].

Internal combustion engines are most commonly used for mobile propulsion in vehicles and portable machinery. In mobile equipment, internal combustion is advantageous since it can provide high power-to-weight ratios together with excellent fuel energy density. Generally using fossil fuel (mainly petroleum), these engines have appeared in transport in almost all vehicles (automobiles, trucks, motorcycles, boats, and in a wide variety of aircraft and locomotives). Where very high power-to-weight ratios are required, internal combustion engines appear in the form of gas turbines [6-9].

All internal combustion engines depend on the exothermic chemical process of combustion: the reaction of a fuel, typically with oxygen from the air (though it is possible to inject nitrous oxide in order to do more of the same thing and gain a power boost).

The combustion process typically results in the production of a great quantity of heat, as well as the production of steam and carbon dioxide and other chemicals at very high temperature; the temperature reached is determined by the chemical makeup of the fuel and oxidizers, as well as by the compression and other factors. The most common modern fuels are made up of hydrocarbons and are derived mostly from fossil fuels (petroleum).

Fossil fuels include diesel fuel, gasoline and petroleum gas, and the rarer use of propane. Large diesels can run with air mixed with gases and a pilot diesel fuel ignition injection. Liquid and gaseous biofuels, such as ethanol and biodiesel (a form of diesel fuel that is produced from crops that yield triglycerides such as soybean oil), can also be used. Engines with appropriate modifications can also run on hydrogen gas, wood gas, or charcoal gas, as well as from so-called producer gas made from other convenient biomass. Internal combustion engines require ignition of the mixture, either by spark ignition (SI) or compression ignition (CI)[10-11].

1.1 Cylinders in I.C engine

The cylinder of an I.C. engine acts as the structural member and retains the working fluid in a closed space with movable piston wall. It is tested to high explosive pressure, which is approximately 3-8 times the maximum compression pressure and high temperature ranging between 1800K and 2400K. Thus the cylinder of an I.C. engine should be able to withstand high working pressure and should be able to transfer heat efficiently without thermal distortion taking place. For small engines operating at low speed, the cylinder block is cast as one piece. However for large engines a separate cylinder liner is used. It facilitates easy repair or replacement of the liner in the event of wear and tear of the cylinder.

1.2 Introductions to cylinder liner

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. This is called Cylinder liner in Japan, but some countries (or companies) call this Cylinder sleeve. Cylinder liners are generally made of closed grained pearlitic cast iron, nickel CI, nickel-chrome CI, cast steel and forged alloy steel. The inner surface of the liner is heat treated to obtain a hard and smooth surface. The basic dimensions of the cylinder liner are determined on the basis of strength and rigidity to prevent ovalization of the liner during assembly and operation. The dimensions should conform to IS: 6750 – 1972. A cylinder liner should be designed and/or checked in the following modes of failure:

- A cylinder liner is designed by treating it as either thick cylinder or thin cylinder depending upon the bore to thickness ratio.
- A cylinder liner should be checked for thermal stress caused by high temperature difference between the outer and inner surfaces of the liner.
- In a cylinder liner, longitudinal stress is produced in addition to hoop stress, though marginal which causes extension of the cylinder.
- The side thrust caused by obliquity of the connecting rod on the cylinder liner induces bending stresses.

Fig -1: Cylinder with piston and cylinder liner

1.3 Materials for dry cylinder liner

The liner material should be strong, hard and corrosion resistant and produce a good bearing surface. The liner materials in order of preference are:

- A good grade grey cast iron with homogenous and close grained structure, i.e., Perlitic and similar cast irons.
- Nickel cast iron and Nickel chromium cast iron
- Nickel-chromium cast steel with molybdenum in some cases.

The cast iron liners can be centrifugally cast. In large engines, usually the cast steel cylinders are used, but may be with cast iron liners. For air-craft engines, the liners are often turned of alloy steel forgings to get very light cylinders. Today's cylinder sleeves come in a wide variety of materials that are appropriate for different applications. They may be manufactured from cast iron or ductile iron, as well as aluminum; each type of metal may also have different levels or grades of quality within them. Manufacturers are the experts when it comes to which type of material is appropriate for which application. Cast iron (or gray iron) is usually a very brittle material, but does a good job when it is contained within an engine. It has good wearability and heat transfer.

Ductile iron is not a single material, but a family of cast irons distinguished by its micro structural features. Engine Builder columnist Norm Brands explains the difference this way: Fig No2.15- Dry cylinder liner without and with collar
"To the naked eye, both types appear to be extremely smooth. Under a microscope, however, there is a clear difference between gray iron and ductile iron. Gray iron has a more textured appearance, with a surface made of larger, coarser-shaped granules or graphite flakes. Ductile iron has a smoother appearance, made of smaller, more rounded graphite nodules."

These graphite nodules act as "crack-arresters" and give ductile iron ductility and toughness superior to other cast irons, and equal to many cast and forged steels. Manufacturers often produce sleeves in different grades, including some that have been engineered and chemically altered for additional strength. Aluminum sleeves may also be used for certain applications, especially for use in aluminum blocks. However, aluminum cylinder liners require a bore coating such as a nickel silicon carbide coating. In most cases, these cylinder liners are reserved for the highest levels of racing.

1.4 Liner failures

I don't know what it is about component failures but we engineers tend to find them fascinating. We may have designed and produced the most elegant piece of hardware, but it's somehow only when it fails - and the more catastrophically the better - that we sit up and take note. Sometimes it is not the fault of the component but perhaps the environment into which it was placed. Sometimes it may have worked well in engines over many years and then suddenly as a result of a single, slight change to the rest of the engine it goes on to fail. And other times we get the strangely bizarre - the failure we could have never predicted, but for our experience, for 100 years. Given a long list of engine failures over time you will therefore not be surprised that the cylinder liner features quite prominently.

An example of the first type of failure is in the machining and preparation of the upper flange and its location in the cylinder block. Poorly machined liner seating or a small particle of dirt trapped between the liner flange and its seat can lead to sudden failure at the assembly stage when the cylinder head is finally tightened. Bending loads introduced into the brittle iron liner by the action of increasing the clamp load can introduce excessive shear stresses, which cause the liner to crack at an angle of 45º all the way around. Characterized by a noticeable 'ping' at the final stage of assembly, the heart - and wallet - drops. Manufacturers, especially engine manufacturers, tend to be a cautious bunch. Components that have served their masters well will often be carried over into new designs, sometimes untouched or with only slight modification. A major change in liner material has, perhaps understandingly, caught out at least two luxury high-performance vehicle manufacturers. Another, however, their liner technology having been proved and apparently unchanged over many years, is starting to alarm owners with low-mileage examples, fastidiously looked after since new.

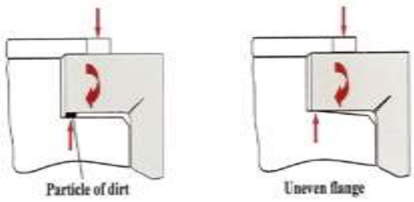


Fig -2: D-shaped Classic crack in the cylinder wall.

The reasons for the failure may or may not be understood by the one-time manufacturer, but with engines well out of warranty the aftermarket is trying to understand if there is a common root to the problem. Scuffed liners as a result of piston seizure would seem to be the outcome, but is this down to marginal lubrication, piston ring sticking or marginal cooling? The cause is not very clear.

Early examples are apparently rarely affected but when increasing the stroke in later versions the failures increased. In some cases, classic D-shaped fatigue cracks also appear in the liner, propagating from the coolant side, suggesting perhaps some form of cooling problem. But is this one problem or two - cooling or lubrication, or perhaps even a combination of the two? At this point the engineers among you will be wondering, and will possibly already have their own thoughts or ideas.

Fig -3: Liner installation failures finally, one of the most bizarre failures.

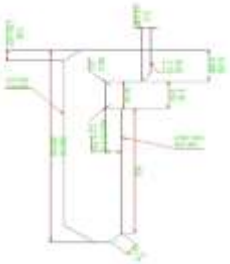
We heard of occurred in a large marine diesel, but it could happen just as easily in a race engine. A shock wave from the combustion of a slow-speed diesel unit traversed the cylinder liner and passed into the cooling water. High coolant temperatures and low cooling water flow rates produced a condition where the repeated pressure waves coming through from the combustion chamber created what is known as cavitations in the liquid next to the liner wall. Alternating pressure spikes and then rarefactions in the liquid caused vapor bubbles to form and then implode again, eventually eroding the external wall of the liner, until eventual failure. Bizarre or not, a one-off occurrence or a common problem, it is difficult to say, but whenever you have high thermal throughput, low coolant flow rates and rapid changes in pressure, the destructive forces of cavitations may not be very far away. The cylinder liner may be a familiar component but it still has the ability to surprise and confuse in equal measure

2. MODELLING OF CYLINDER LINER

2.1 A Hino – X engine cylinder Dry Liner used in one of Ashok Leyland model specifications

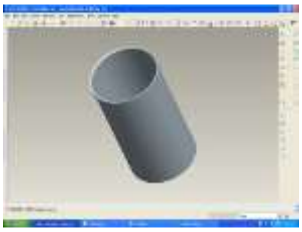
- Manufacturer: Kusalava Industries", Vijayawada.
- Material of Cylinder Liner: Cast iron
- Liner coated Material: Ceramic (psz), Al_2O_3, Nickelcrome alloy steel with 0.3mm thick
- Thickness of Dry cylinder liner: 1.5 mm
- Total length of Dry cylinder liner: 200.50 mm
- Cylinder liner input temperature: 558K
- Max pressure: Pressure -4.5N/mm^2
- Type: Overhead valve vertical diesel engine 6 cylinder in line
- Bore: 104.008 mm
- Stroke: 120.7 mm
- Cubic capacity: 6075 C.C
- Compression ratio: 16.1

- Brake power: 83.25 kW at 2500 r.p.m
- Torque: 379 Nm at 1700 r.p.m
- Cylinder head: Detachable one piece casting
- Cylinder block: one piece casting liner prefinished, press fit, flange located



(All dimensions are in mm)

Fig -4: Line diagram for dry cylinder liner



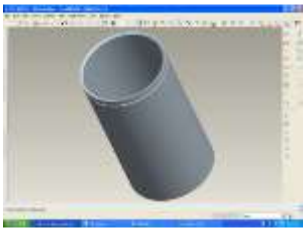


Fig -5: Dry Cylinder Liner without Fin

Fig -6: Cylinder Liner with Fin (Inside Cylinder)

2.2 Mechanical and thermal properties of materials

Table -1: Properties of materials

Type of materials Property	cast iron	Aluminum alloy 6101	Ceramic(psz)	Al_2O_3	Nickelcrome alloy steel
Thermal conductivity W/KgK	25.2	220	3	25	12
Specific heat J/KgK	506	895	418.68	880	500
Density Kg/mm3	0.00000719	0.0000027	0.00000719	0.0000039	0.0000074
Young's modules Mpa	157000	69000	157000	353000	115000
Poisson ratio	0.283	0.32	0.31	0.22	0.32

3. RESULTS AND DISCUSSION

3.1 Uncoated dry cylinder liner

- For dry Cylinder Liner – **Cast Iron**
  - Element Type: solid 20 nodes 90
  - Material Properties:
  - Thermal Conductivity – 25.2W/mK
  - Specific Heat – 506 J/kg K
  - Density - 0.00000719kg/mm^3
- For Fin – **Aluminum Alloy 6101(take** thickness of Fin is 7mm)
  - Element Type: solid 20 nodes 90
  - Material Properties:
  - Thermal Conductivity – 220W/mK
  - Specific Heat – 895 J/kg K
  - Density - 0.0000027kg/mm^3

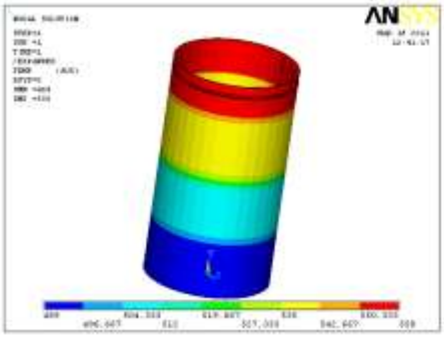


Fig -7: Nodal temperature

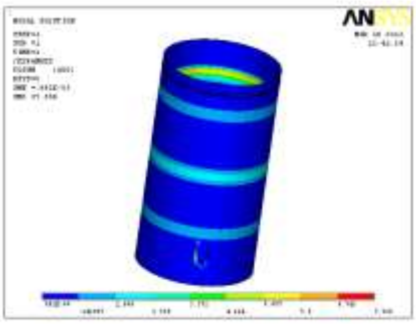


Fig -8: Thermal gradient

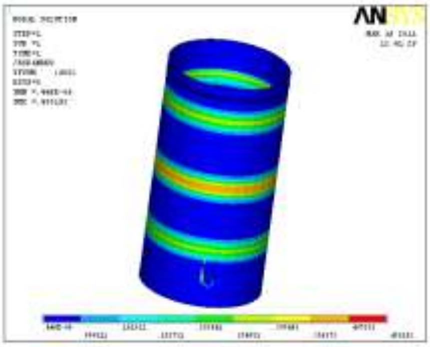


Fig -9: Thermal flux

3.2 Coated dry cylinder liner

3.2.1Cylinder liner coated with ceramic (PSZ)

- For liner coating – **Ceramic (PSZ)**
  - Element Type: solid 20 nodes 90
  - Material Properties:
  - Thermal Conductivity – 3W/mK
  - Specific Heat – 418.68 J/kg K
  - Density - 0.00000575kg/mm^3

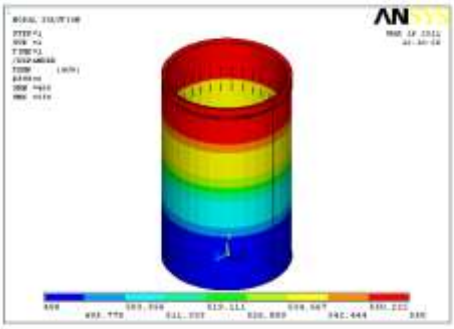


Fig -10: Nodal Temperature

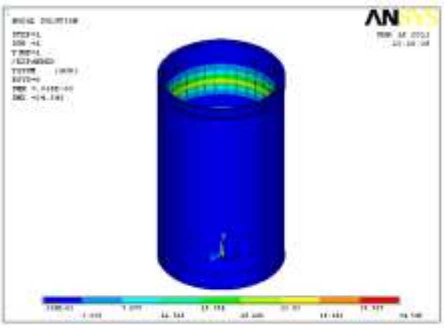


Fig -11: Thermal gradient

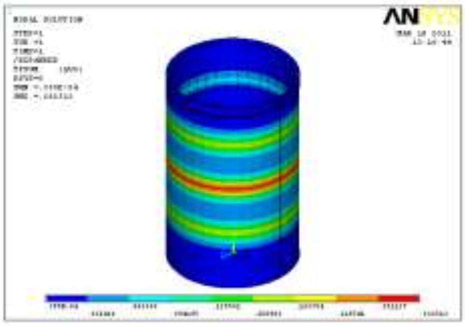


Fig -12: Thermal flux

3.2.2 Cylinder liner coated with aluminium oxide (Al_2O_3)

- For liner coating; **Al_2O_3**
  - Element Type: solid 20 nodes 90
  - Material Properties:
  - Thermal Conductivity – 25W/mK
  - Specific Heat – 880 J/kg K
  - Density - 0.0000039kg/mm^3

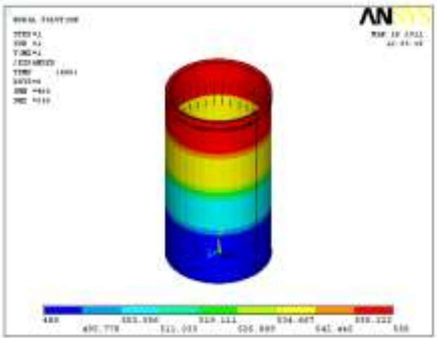


Fig -13: Nodal Temperature

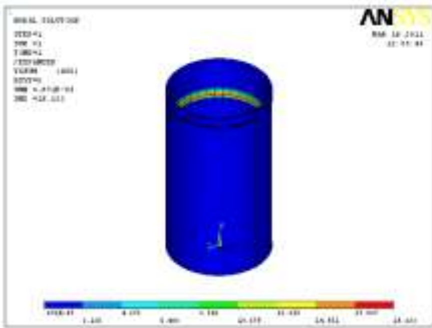


Fig -14: Thermal gradient

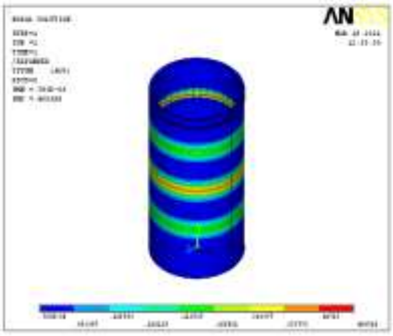


Fig -15: Thermal flux

3.2.3 Cylinder liner coated with Nickel chrome alloy steel

➢ For liner coating – **Nickel chrome Alloy Steel**

- Element Type: solid 20 nodes 90
- Material Properties: Thermal Conductivity – 12W/mk
- Specific Heat – 500 J/kg K
- Density - 0.00000745kg/mm^3

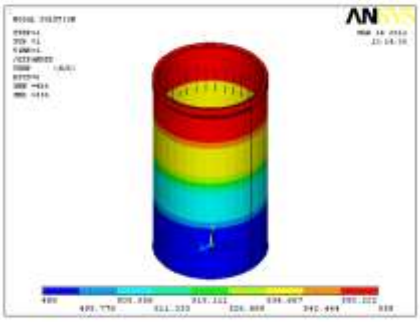


Fig -16: Nodal Temperatures

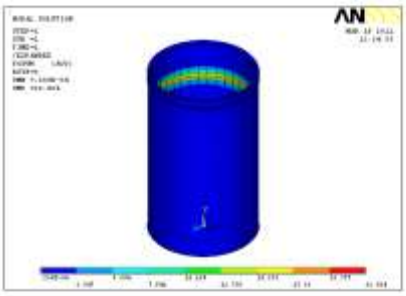


Fig -17: Thermal gradient

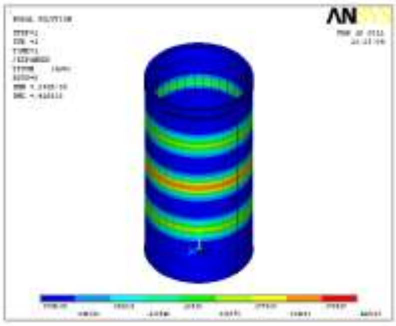


Fig -18: Thermal flux

Table -2: Results summary

	Nodal Temperature (K)	Thermal Gradient (K/mm)	Thermal Flux (W/mm^2)
Without (Coating)	558	7.586	0.458192
Ceramic (PSZ) Coating	558	34.545	0.282513
Al_2O_3 (Coating)	558	19.223	0.480566
Nickel Chrome Alloy steel(Coating)	558	22.924	0.416832

4. CONCLUSIONS

The following conclusions drawn from the present work are as follows

For un-coated materials

- Due to thermal analysis (nodal temperature, thermal gradient, thermal flux) and structural analysis (displacement, von-mises stress and strain) are more values gives poor results for un-coated materials used for dry cylinder liner.

For coated materials

- Due to thermal analysis (nodal temperature, thermal gradient, thermal flux) and structural analysis (displacement, von-mises stress and strain) gives better results than uncoated materials used for dry cylinder liner.
- For the coated materials the ceramic (psz) dry cylinder liner gives minimum values for thermal flux equal to 0.282513W/mm

- For the coated material Al_2O_3 gives minimum values for displacement, (0.032518mm) von-mises stress(38.31N/mm^2) and strain(0.473e$^{-3)}$ which is the best material
- For the coated material Nickel Chrome Alloy steel gives less values for displacement (0.035057mm), strain(0.488 e$^{-3)}$and thermal gradient(22.924) K /mm which is better material
- The alloying elements (coated materials) help to give the better performance of the dry cylinder liner and engine in total

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