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HEAD GASKET FAILURE ANALYSIS

Abhilash J. Nair

IInd yr M.Tech Automotive Engg

Dept. of Mechanical Engg

Amrita Vishwa Vidyapeetham

Email: abhilashjpn@gmail.com

C. Lakshmikanthan

Asst. Prof. Dept. of Mechanical Engg

Amrita Automotive Research & Technology Centre

Amrita Vishwa Vidyapeetham

Email: c_lakshmik@cb.amrita.edu

Abstract-

Head gasket is the name given to the mechanical seal between cylinder block and cylinder head. It is expected to seal gases from the combustion chamber, the coolant and the lubricant from one another during the varying ranges of temperature and pressure conditions during engine running caused by varying engine speeds and loading.

The stopper area is the most important part of the head gasket. From the literature, it was understood that approximately 60-80% of head bolt stresses act on stopper area. This makes the designing of stopper area based on head bolt stresses critical.

This paper aims at understanding the structural behavior of various proposed gasket stopper designs and thereby propose a new design ; using the numerical simulation used by Chang-Chun Lee et al, 2005 as this design's validation technique.

Keywords: Head gasket; stopper; head bolt.

Legends:

E - Young's Modulus **(**GPa**)**

μ - Poisson's Coefficient

α –Thermal Expansion Coefficient (/K)

k- Thermal Conductivity (W/m K)

ρ- Density (kg/m^3)

Introduction

Head gaskets play an important role in maintaining the integrity of internal combustion engines. They are under high compressive stresses by the head bolts. Around 70% of the stresses are used to seal the combustion gases and the rest are used to seal the coolant and lubricant paths.

Finite element analyses are gradually being depend on for the improvement of the design and to decrease overall production time of powertrain components. Multi-layer steel head gaskets are important, passive sealing components that exist in almost all internal combustion engines and are crucial for proper engine performance. In industry, there currently exist many different approaches for studying this component using finite element analysis.

This research involves first understanding the nature of head gaskets that are used in Internal Combustion Engines. From the literature review it can be concluded that the behavior of gasket stoppers to sealing pressure was an area of improvement. The CAD modeling of the relevant components of Internal Combustion Engine was done using SOLIDWORKS 2013 whose meshing and analysis was done using ANSYS WORKBENCH.The research also attempts to improve the characteristics of gasket stoppers towards the minimum contact pressure criteria by a comparative study involving a new stopper configuration with commonly used designs. The research process had its results validated against the numerical simulation done by Chang Chun Lee et al.; 2005; which had been already experimentally validated.

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Methodology:

The methodology adopted in this research was based on the technique of numerical simulation as followed by Lee et al., 2005; due to its following advantages:

a. Lesser hitches of boundary conditions,

b. Reduction of the element size of the finite element analysis.

The numerical simulation as done by Chang Chun Lee et al,2005 was first carried out for the purpose of standardization of the procedure; based on which further work in this research was done.

1. Fe Model

The FE Model used in this research was based on the FE Model used by Chang Chun Lee et al., 2005.The model was a 4 stroke 4 cylinder gasoline engine. The CAD modeling was done using SOLIDWORKS 2013 instead of the PRO E modeling used by Chang Chun Lee et al., 2005.

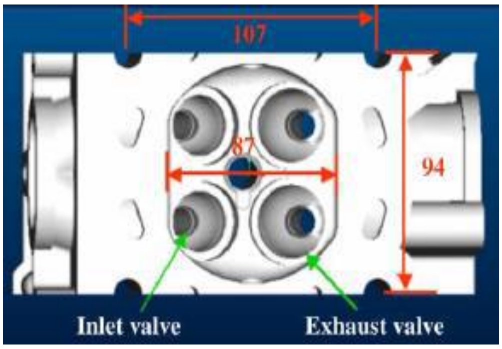
For simplifying the procedure, Chang Chun Lee et al., 2005 had adopted the following assumptions, which are also a part of this research:

a. Due to the structural symmetry of the 4 cylinders; the 2nd cylinder head was removed to reduce the calculated time

b. For analyzing the bolt pre-stresses; a half model was required to understand the gasket sealing efficiency.

The below figures show the CAD models with dimensions used by Chang Chun Lee et al.; 2005 and the ones used in this research.

Fig.1: Cylinder Head (a) By Lee et al., 2005 (b) used in this research



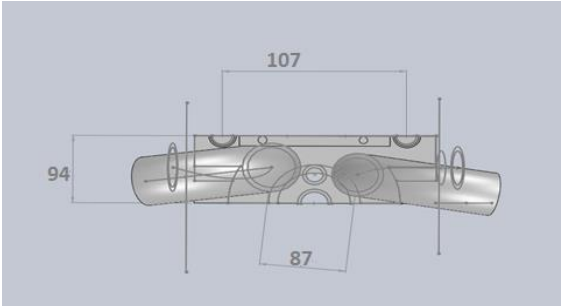
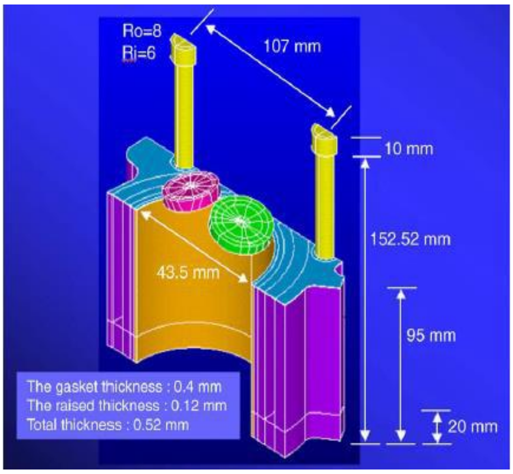


Fig.2: Cylinder Block (a) By Lee et al., 2005 (b) used in this research



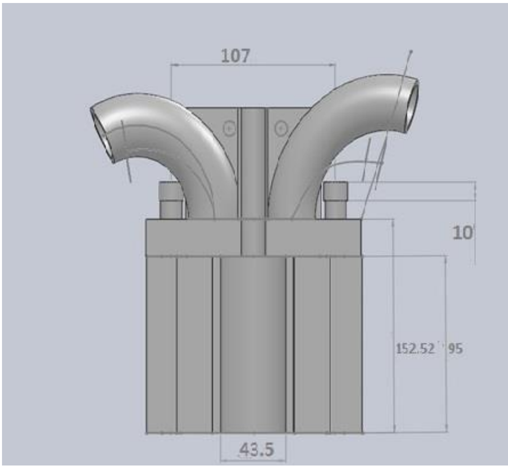
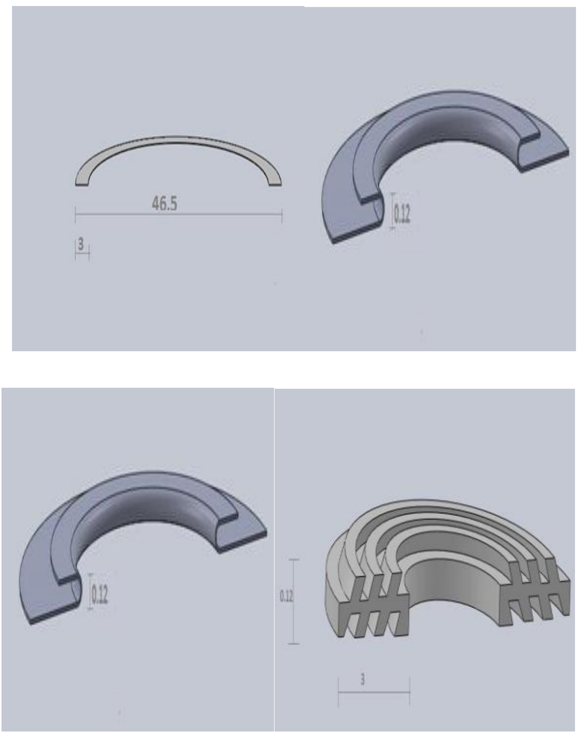


Table 1: Properties of each part used

Part	Material used	E	μ	α at 300 ^{o}C	k	ρ
Exhaust	214N	215	0.290	17.5 *10^(-6)	15.3	7610
Inlet	EN52	90	0.290	11.2 *10^(-6)	23.4	7740
Cylinder head	Al Alloy	71	0.330	2.4 e(-5)	177.2	2700
Cylinder block	Al Alloy	71	0.330	2.4 e(-5)	177.2	2700
Liner	Cast Iron	107	0.295	1.2 e(-5)	0.0591	7200
Bolt	SCM 435	205	0.29	16 e(-6)	N/A	7700
Gasket	301 SS	Multielastic	0.29	1.9 e(-5)	42.7	7880

Fig.3: CAD model of Flat, folded, wave and rhombus Stoppers



2. Analysis Technique

Here, major loading conditions in engine operation were adapted from Chang Chun Lee et al., 2005. The analysis software used was ANSYS WORKBENCH 12.1.

2.1 Thermal Exploration

Chang Chun Lee et al., 2005 had used the results of the thermal analysis involving the temperature spread of the cylinder head at 6500 rpm. Results showed that the spark plug area had the highest temperature in the cylinder head. It was also assumed that the bolts, valves and other such components (except the inlet and exhaust valves) do not contribute much to the heat transfer in cylinder head.

2.2 Structural Exploration

Based to the loadings on the head gaskets during different engine running conditions, the model which is assumed to be linear-elastic is divided into three parts:

a. ***Assembly loading***

The effect of bolt pre-stressing on the head gasket during assembly loading is analyzed using the static structural system. Here the underside of the cylinder block was fixed.

b. ***Thermal loading***

Here, nodal temperatures obtained from thermal exploration were assigned to respective nodes of the FE model to find thermal stress/strain on cylinder head using steady-state thermal system. The boundary conditions are the same as that of assembly loading.

c. ***Gas pressure***

The pressure caused by combustion chamber changes according the engine working cycle. For simplifying the analysis, the average gas pressure of 6.7MPa was adapted from Chang Chun Lee et al.;2005 and applied for the conditions of cold starts and hot firing.

3. Mesh Setup

The count of the nodes and elements as per the FE model used by Chang Chun Lee et al, 2005 was 17880 and 32430 respectively. The count of the nodes and elements in the FE model used in this research were 22939 and 30951 respectively.

Results And Discussions:

Here, the weakest contact pressure was used as the parameter to investigate the gasket sealing's efficiency. The results were summarized as follows:

1. **Cold Assembly**

This was the condition of the vehicle when it is at rest. Here the maximum stresses are induced on the head gasket due to the head bolts. Results revealed that weakest contact pressure developed on the head gasket occurred at the elevated portion of the inner ring between two neighboring combustion chambers. This was because the gap between the bolts and the preceding location of the gasket was the highest. Maximum contact pressure varied from inlet area to exhaust area due to its structural asymmetry.

2. **Cold Starts**

Here the conditions of assembly loading as well as gas pressure were used. Location of minimum contact pressure was same as that in cold assembly; except that the magnitude diminishes due to gas pressure direction being opposite with respect to loading due to bolt pre-stressing. The cold start condition was simulated using the loading consisted of both the assembly loading and the gas pressure. The spread of contact pressure and the position of the least effective gasket sealing are the same as cold assembly condition. The sealing capacity of the gasket decreases substantially since the active direction of the gas pressure was opposite to the pre-stressing force of the bolt.

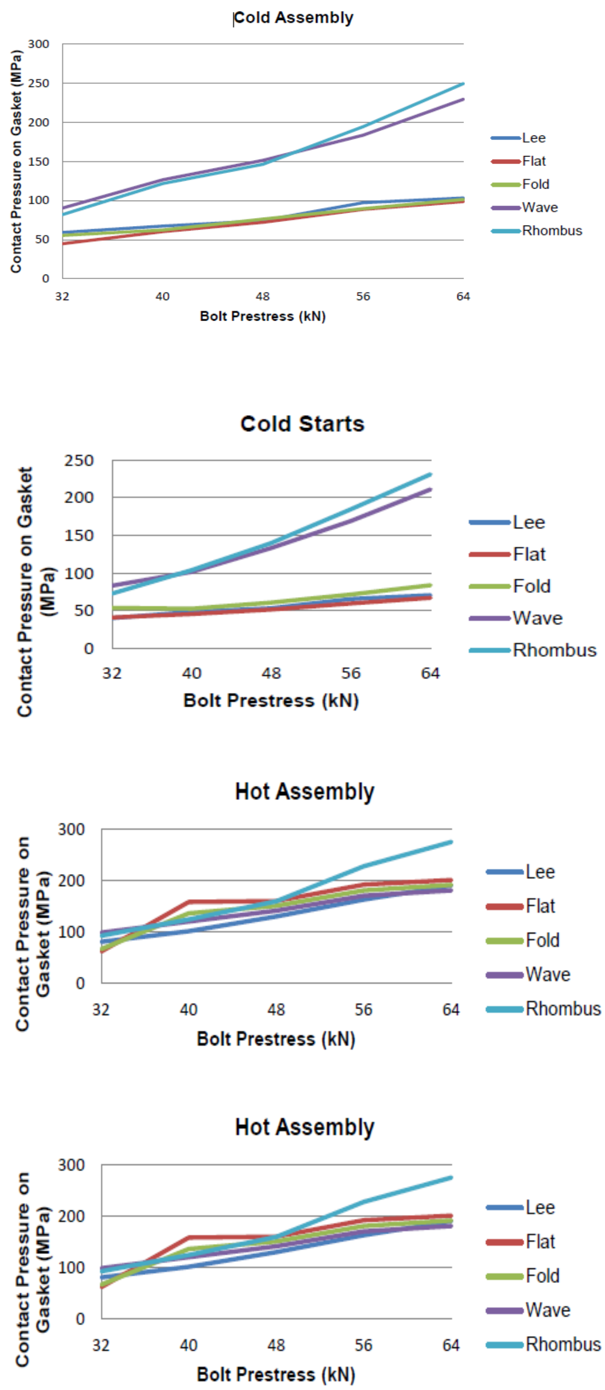
3. **Hot Assembly**

This scenario represented the engine when it was in idle. Here loading occurs due to bolt pre-stressing and thermal loads. The results revealed that gasket sealing efficiency increased.

4. **Hot Firing**

Here the conditions of assembly loading, thermal loading and gas pressure were used. The results revealed that the distribution of contact pressure was similar to that of hot assembly except that the magnitude was decreased.

Fig. 4: Graphs showing the variations in minimum contact pressure for the stopper types at varying bolt loads. [Cold assembly, cold starts, hot firing and hot assembly (taken clockwise)]



Inferences:

In this investigation, structural examinations of head gaskets under various conditions of loading were accomplished by means of the technique of numerical simulation in finite element analysis. The head gasket failure analysis is carried out keeping the minimum contact pressure present between the cylinder head and gasket as the criteria of interest.

A comparative study was done for various commonly used types of stopper designs and an attempt was made to improve the sealing capacity of head gasket assembly. The collective output of the above research was a new type of stopper design; which seemed to work satisfactorily under the minimum contact pressure criteria of interest. The procedure followed to do the comparative study is based on the numerical simulation technique carried by Chang Chun Lee et al.; 2005; which had been experimentally validated.

The stopper design was subjected to varying bolt loads under varying engine conditions; assuming certain conditions. Even though this research opens opportunities to gain another stopper design; further testing of the same is required before commercializing.

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