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Fatigue Analysis of a Piston Ring by Using Finite Element Analysis

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Abstract: *Finite element models were used to calculate the stresses in a piston ring, for centrifugal forces, gas pressure, piston to cylinder contact and thermo-mechanical loading. A fatigue analysis superimposed the four loading conditions and calculated the fatigue life at each node on the model, adjusting the materials fatigue properties for the effects of nodal temperature. The identification of fatigue-critical locations, and the calculated fatigue lives, showed good agreement with test results. In this work, the damaged piston ring was analyzed for its fatigue strength using ANSYS commercial finite element software. Piston ring of diesel engine was taken for the analysis. Damages initiated at the crown, ring grooves, pin hole sand skirt are assessed. A compendium of case studies of fatigue-damaged piston ring is presented. An analysis of both thermal fatigue and mechanical fatigue damages is presented and analyzed in this work.*
Keywords*: (Piston Ring, Fatigue, Gas Pressure, Thermo-Mechanical Loading. Ring Grooves).*

I. Introduction

Piston ring materials and designs have evolved over the years and will continue to do so until fuel cells, exotic batteries or something else makes the internal combustion engines obsolete. The main reason of this continuous effort of evolution is based on the fact that the piston may be considered the heart of an engine .

The piston is one of the most stressed components of an entire vehicle Pistons must also be light enough to keep inertial loads on related parts to a minimum.

The piston also aids in sealing the cylinder to prevent the escape of combustion gases. It also transmits heat to the cooling oil and some of the heat through the piston rings to the cylinder wall.

As one of the main components in an engine, pistons technological evolution is expected to continue and they are expected to be more and stronger, lighter, thinner and durable. The main reason is because the mechanical efficiency of an engine is still low and only about 25% of

the original energy is used in brake power. Not with standing this technological evolution there are still a significant number of damaged pistons Damages may have different origins: mechanical stresses; thermal stresses; wear mechanisms; temperature degradation, oxidation mechanisms; etc. In this work only mechanical damages and in particular fatigue damages will be assessed.

Fatigue is a source of piston ring damages. Although, traditionally, piston damages are attributed to wear and lubrication sources, fatigue is responsible for a significant number of piston ring damages. And some damages where the main cause is attributed to wear and/or lubrication mechanisms may have in the root cause origin a fatigue crack. Fatigue exists when cyclic stresses/deformations occur in an area on a component. The cyclic stresses/deformations have mainly two origins: load and temperature. Traditional mechanical fatigue may be the main damaging mechanism in different parts of a piston depending on different factors. High temperature fatigue (which includes creep) is also present in some damaged pistons ring. Thermal fatigue and thermal–mechanical fatigue are also present in other damaged pistons.

In this work, different pistons, from different kinds of engines: train engines; motorcycle engines; and automotive engines will be presented. Different damage mechanisms where fatigue prevails over other damaging mechanisms will be assessed.

For better understanding of the damaging mechanism different analytical tools, such as finite element analysis, metallurgical analysis, etc., will be used whenever they are necessary for a clear understanding of the damaging mechanism. A finite element linear static analysis.

Experimental work

The fatigue-damaged piston rings assessed on this work may be divided into two categories: the mechanical and high temperature mechanical damaged pistons and the thermal and thermal–mechanical damaged pistons rings.

The mechanical and high temperature mechanical damaged pistons may be divided according to the damaged area: piston head; piston pin holes; piston compression ring grooves; and piston skirt. The analysis, in this work, will be made according to this classification.

Material Specification Material	Minimum Bending Strength **) (N/mm^2)	Modulus of Elasticity **) 10^3 x (N/mm^2)	Grade
	Tensile strength *)		
GOE 61 - 18% Cr-Steel	1300	230	Martens tic
GOE 65C - 13% Cr-Steel	1150	210	Chromium Steel
GOE 64 - SAE 9254	1020	206	Spring Steel
GOE 52 - KV1 GOE 56 - KV4	1300 1300	>150 >150	Nodular Cast Iron, unalloyed, heat-treated
GOE 44	800	>165	Malleable Cast Iron
GOE 32 - F14	650	130 - 160	Grey Cast Iron, alloyed, heat-treated
GOE 12 - STD GOE 13	350 420	85 - 115 95 - 125	Grey Cast Iron, unalloyed, paralytic

*) Bending strength not measurable on steel rings
**) as per GOE Specification

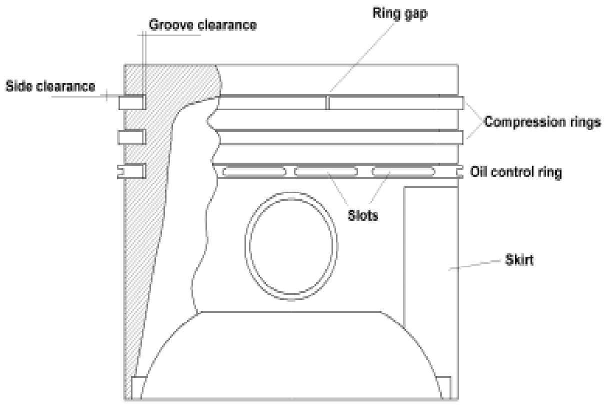

Fig 1. Compression Rings or Pressure Ring.

The details of the compression ring

Outside diameter of the ring : 59.5mm
Inside diameter of the ring : 56mm
Width of the ring : 3mm
Load on the ring : 420Mpa

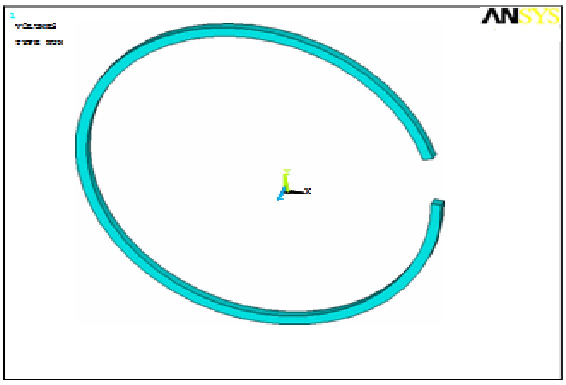

Fig 2. Modeling of compression ring

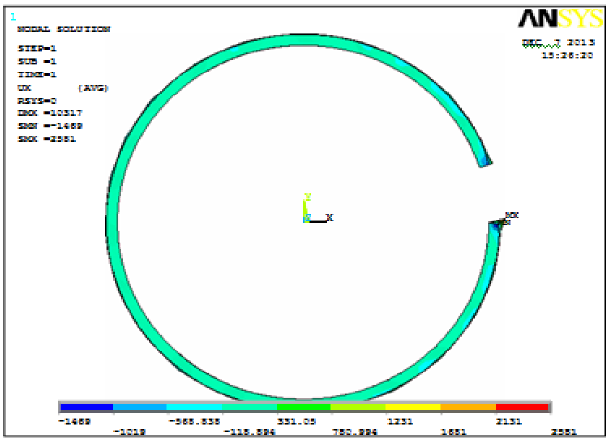

Fig 3 Deformed shape shear stress of piston ring

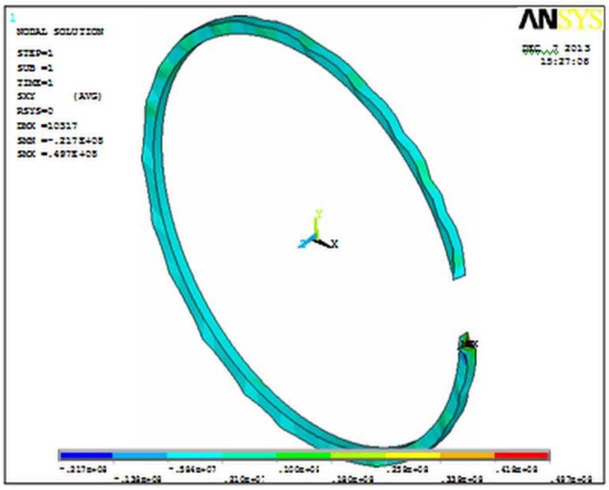

Fig 4 Bending strength of the compression ring

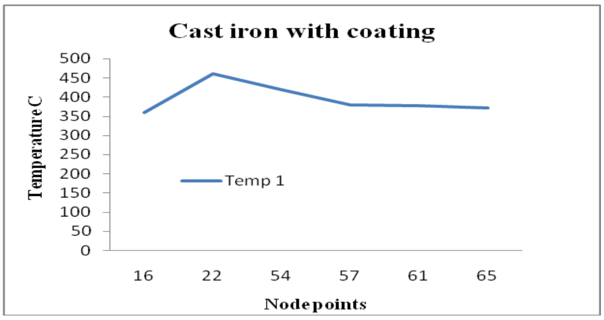

Fig 5 Piston ring with coating material

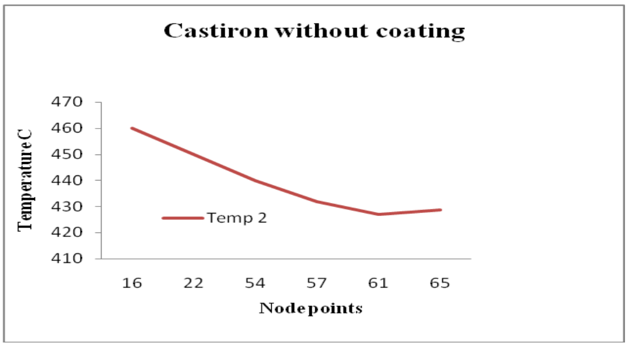

Fig 6 Piston ring without coating material

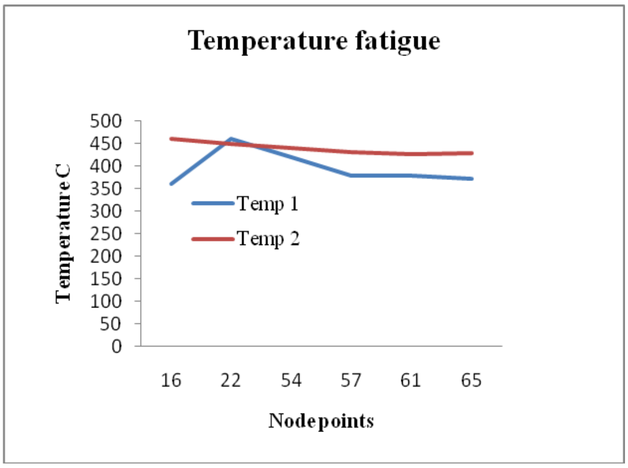

Fig 8 Comparison of temperature fatigue

The above fig shows the thermal stresses due to the vertical distribution are represented in Fig. There is a homogeneous and regular gradient of temperature on the radial direction along the head of the component. It is observed that the bowl ring area is the area where temperatures are higher. Thermal deformations under the operating piston ring temperature are constrained by the surrounding material. This causes large compressive stresses on the total piston ring circumference that often exceed the yield strength of the material. After creep relaxation of the high compressive stresses and when the piston gets cold creep effect gives rise to tensile residual stresses on the piston ring. This cyclic stresses origins cracks distributed all around the ring area.

II. Conclusion

The conclusion is that could be drawn from this work is that although fatigue is not the responsible for biggest slice of damaged pistons, it remains a problem on engine pistons and its solution remains a goal for piston manufacturers. And it will last a problem for long because efforts on fuel consumption reduction and power increase will push to the limit weight reduction that means thinner walls.

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