

Design and Analysis of Toroidal Piston Using Ansys

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Abstract

A toroidal piston bowl was designed using Ansys software. Temperature distribution and total heat flux are presented in this work. We begin by presenting works of different authors on Toroidal piston and related subjects. By presenting our own experiment and conclusions later on in this paper, we provide a comprehensive analytical study of a Toroidal Piston using the Ansys software.

Keywords: *Piston, Heat Flux, Temperature and Boundary Condition*

INTRODUCTION

The cast iron pistons were superseded by aluminium alloy piston around the year 1920 (Sarkar 1975). Cole G.S. and Sherman A.M.(1995) explained that a considerable interest had been grown in replacing cast iron and steel in automotive component like piston with light weight aluminium alloy casting to improve the performance and efficiency. Haque M.M and Young J.M. (2001) referred the low expansion group of aluminium–silicon alloy as piston alloy, since this group of alloy provides the best overall balance of properties. Near eutectic aluminium silicon

piston alloy exhibit complex fatigue behavior due to their multicomponent microstructure (Moffat et al 2005). Aluminium alloys are ready to cast by all common casting techniques (Budinski 2001). In order to improve the wear performance, a metal based insert is reinforced with the base alloy. Cast iron and steel inserts normally reinforced with the light weight alloy during the casting process. To achieve the bonding between aluminium and cast iron, special patented processes are used. The presence of dirt and oxide induces trouble to the bonding between insert and alloy. The component

was coated with a tin layer by dipping or electro plating and subsequent heat treatments were carried out before casting (Cole and Andrew T 1991). Gravity die casting and the pressure casting methods are used for the Al-Fin process. A special casting technique derived from the so called Al-Fin process is used in the manufacture of piston by gravity die casting and squeeze casting method. Al-Fin process is also known as Al-Fer process which is achieved by diffusion bond between the insert and aluminium alloy. When the liquid aluminium strongly reacts with iron, it forms brittle intermetallic compounds at the reinforcement region. The rate of growth of the intermetallic layer is limited by diffusion of reacting species through intermetallic layer and not by the interfacial chemical reaction (Vaillant Ph and Petit J.P. 1995). However, the low hardness of the light alloy and higher service temperature during the piston operation do pose some difficulties (Snee 1985).

A piston is formed by casting under pressure around an insert, the body being made of aluminium or aluminium alloy and the insert being made of a porous layer having a thickness 20 to 50 times the pore diameter and completely filled with the

piston body metal which projects from the body into the pores of the insert. Normally steel and cast iron are used as reinforcement at aluminium alloy at high load bearing region. In order to improve performance, a porous ceramic insert can also be used as reinforcement. During the squeeze casting process the pores of ceramic insert is filled with liquid aluminium alloy (Kohnert 1982). To produce a good bond between ferrous metals and aluminium alloys liquid metal, hot dipping process was developed. To improve the wettability and bonding of the steel insert, first coat it with thin aluminium layer. Due to the superior workability, high thermal conductivity, high resistance to wear, grey cast iron is employed as insert material (Birigt Hudelmair 2000). According to Morishita (1981), in internal combustion engines particularly diesel cycle engine, piston with aluminium based alloy is provided for the purpose of better heat radiation and lower weight. Such problem can be alleviated by casting the aluminium alloy around the insert body. For the better adhesion the dipping time of the insert was varied from 3-7 minutes. The density of the insert was substantiated by including copper based alloy to fill the pores of the sintered austenitic ferrous alloy body.

Durrant G. et al (1996) explained about the aluminium alloy reinforced with mild steel insert by squeeze cast technique. The bonding of aluminium silicon alloy with the reinforced insert plays a vital role in improving the service life of the component. The importance on the suitable registry between these reinforced insert and alloy is restricted by the surface contaminants and surface oxides (Stefaniay et al 1987). The aluminium alloy casting having a porous metal insert improves the bonding strength by squeeze casing technique. The porous insert may be pre heated before the casting process in order to improve packing (Takasuga 1990). The insert can also be coated by electro plating method which was explained by Han and More K.L. (2003). A stamped steel insert is used as an insert in metal die cast articles. The insert includes first and second interconnected stamped steel insert halves spaced from one another at certain locations to define a void. The edges of the insert lie below the surface of the casting to avoid bimetallic machining. However this is still in the early stages of development (Shimmell 1998). Donomoto (1985) discussed a method for the porous reinforcing material. It is heated up to a temperature substantially above melting point of the matrix metal. Then the molten matrix

metal is infiltrated into the porous structure of the reinforcing material under a substantial pressure. Then the combination of the reinforcing material and the matrix metal infiltrated there into is cooled down to a temperature below the melting point of the matrix metal, while maintaining the above mentioned substantial pressure.

A ceramic insert is adapted on the head portion of the piston and connected to the same by mechanical locking. The ceramic insert is provided with pores at least on the portion engaging the piston head. The pores have sizes which enable them to be filled with the light alloy during the manufacture of the piston by the squeeze casting method (Mahrus 1988). Piston can be formed in two parts. The main part is formed by gravity die casting from aluminium or aluminium alloy and a second part of the piston is formed by a squeeze casting process to produce a material which is stronger and more resistant than the gravity die cast aluminium or aluminium alloy. The two parts are then electron beam welded together to form the complete piston. The squeeze cast portion may be reinforced with whiskers or fibers to further improve its properties. This method of construction has the benefit that only a smaller portion

of piston is formed by the more expensive and time-consuming squeeze casting process. This is the benefit in large diesel pistons (Avezou 1987). David. J (1985) worked on the provision of a wear resistant insert for pistons of light weight alloys. The insert comprises an annular ring of wear resistant material which has a cylindrical peripheral edge. The annular ring has at least one projection or tab which extends outward from the peripheral edge for positioning and supporting the annular ring in a die cavity during the casting. Ceramic inserts are embedded in thermally loaded zones as heat insulation in light metal castings for use in internal combustion engines. To provide a firm joint between the insert and the light metal, a metallic material which resists creep and relaxation is shrunk on the insert before it is embedded (Sander 1985). The reinforcement of the crown of a piston of aluminium or aluminium alloy for an internal combustion engine comprises the preparation of a reinforcement member which need not be exactly in the shape of disc, and it may be of any convenient shape (Graham 1986). Brittle intermetallic phases observed at interface reduce the life of component. Such problems can be alleviated by suitable techniques such as vibration assisted casting and heat

treatment. Piston industries require such techniques (Dwivedi et al 2007).

Typical heat treatment cycles for aluminium alloy were explained in a detailed manner by Budinski (2001). All treatable alloys are strengthened by precipitation hardening (Mike Meier 2004). The mechanical properties of the piston were optimized by solution heat treatment and quenching operation followed by a precipitation treatment (Cole and Andrew T 1991). Durrant G. et al (1996) explained that the wear performance of piston alloy can be improved by solution, ageing and precipitation heat treatments. Yeremenko et al (1981) identified the formation of a brittle layered intermetallic phase during the interaction of solid metal with liquid. There are many reports on ternary (Al-Fe-Si) compound system. The ternary compounds can be identified using the phase diagram (Ragavan 2002). There are three intermediate phases in the system with restricted ranges of homogeneity: FeAl_2 , Fe_2Al_3 , and FeAl_3 .

There is a need for machining to achieve the desired dimension and surface finish. The metal cutting industries continue to suffer from a major drawback of not running the machine tools at their

optimum operating conditions (Hari Singh and Pradeepkumar 2005). Tonshoff. H.K (2000) highlights the functional behavior of machined parts, decisively influenced by the fine finishing process, which represents the last step in the process chain, and can as well be undertaken by cutting. The patent details of Hessman Ingemar (2005) revealed that the cemented carbide cutting tools can be employed to machine bimetallic components. Coated cemented carbide cutting tool inserts are used for bimetal machining under wet condition at moderate cutting speed of engine blocks formed from alloys of cast iron and aluminium. Moderate cutting speed is used to machine bimetallic bodies with cemented carbide cutting tool, which results in lower productivity. Today there is a high demand for the development of environment friendly and cost effective cutting technologies including high performance tool materials suitable for dry speed cutting (Hovsepian et al 2005).

Zone Ching Lin and Din yan chen (1995) studied on Cubic Boron Nitride (CBN) a sintered product, which can be used as a cutting tool material for hard turning and for higher productivity. CBN tool has various characteristics like excellent wear durability, high hardness and good thermal resistance. The cost of the tool is

extremely high and it is 10-20 times more than carbide tools (Steven Y Liang 2003). The improved qualities of the machined surface and associated higher productivity compensate the high initial cost of these CBN tools. Precision finish turning has the potential to replace grinding in some application. According to Kivilcim Buyukhatipoglu (2003), due to the recent developments of cutting tools and machine tool structural rigidity hard turning is an alternative to some of the grinding process which reduces the cost and cycle time. High content of CBN tools (90%) give better surface finish (Radu Pavel 2004). Mehdi Remadna and Jean Francois Rigal (2006) give the importance of geometry of the cut to determine the life time of a CBN tool. High abrasion resistance is required for increased performance if a tool possess coarse grain size (Ding.X et al 2005).

For machining bimetallic component, two different tools and two different cutting parameters were used earlier. Due to frequent change of tool, the cycle time is increased. Hence, it is required to implement a single tool for machining both metals. Literature on machining and surface integrity of such bimetallic components is scarce at present. This study has made an attempt to address such

problems in machining of bimetallic components.

The quality design first proposed by Taguchi in 1960s is widely applied because of consistent improvement in the quality of the product (Chih Wei chang and chun pao kuo 2006). In the last several years, the use of designed experiments in manufacturing and engineering design environments has become increasingly popular through the introduction of the ideas of Dr. G. Taguchi (Henry S. Lewandowski 1989). Taguchi method based robust design approach has produced a unique and a powerful quality improvement discipline that differs from traditional process (Roy R. 1990). Robust design is based upon the technique of matrix experiments. Experimental matrix is of special orthogonal array, which allows the simultaneous effect of several process parameters to be studied efficiently. Product or process design has a great impact on the life cycle, cost and quality (Tapan P. Bagchi 1993). The number of degrees of freedom is calculated from the number of parameters identified and their number of levels of variation. Yang Y.H. and Tang (1998) used orthogonal array for signal to noise ratio and analysis of variance to determine cutting parameters and to find the main

parameters affecting the turning process considering the tool life and surface roughness. Paulo davim and Antonio C.A.(2003) presented a study on influence of cutting velocity, feed and cutting time in turning metal matrix composites. Benardos and Vosniakos (2002) have presented a neural network model for prediction of surface roughness. In order to monitor the bonding region quality ultra sound is used (Mark willcox 2003). Ravindra H.V et al (1993) analyzed the tool wear based on cutting forces on turning operation. The cutting forces generated in metal cutting have a direct influence on heat generation, tool wear or failure, quality of machined surface and accuracy of the work piece (Suleman yaldu 2006). Analysis of cutting forces in fine turning is most frequently related to work piece material hardness and strength under different machining conditions (Grum and Kisin M 2003). Material hardness and strength as well as machinability can be related to the material microstructure. Tool wear is mainly caused by the formation of built up edge and adhesive layer (List et al 2005, Nouari et al 2003).

The cutter geometry, work piece hardness and feed have the most significant effect on cutting forces (Li Qian and Mohammad

Robiul Hossan 2007).Wear on tool face was measured by analyzing the crater due to the action of chip flowing along the face (Geoffrey Boothroyd 2005). WuyiChen (2006) explained that radial thrust cutting force was the largest among three cutting force components and the most sensitive to the changes of cutting edge geometry and tool wear while machining medium hardness steel with CBN tool. Mustafa Gunay et al (2006) identified the influence of rake angle on cutting force. It has been proved that the mean cutting force decreases, as rake angle increases.

MATERIALS & METHODS

The materials used for piston is mainly Alluminium alloy. Cast Iron is also used for piston as it possesses excellent wearing qualities, co-efficient of expansion. But due to the reduction of weight, the use of alluminium for piston was essential. To get equal strength a greater thickness of metal is essential. Thus some of the advantage of the light metal is lost. Alluminium is inferior to Cast iron in strength and wearing qualities and hence requires greater clearance in the cylinder to avoid the risk of seizure.

The piston made by the alloy of alluminium produces less inertia forces there by rotating the crankshaft more smoothly. The heat conductivity of

alluminium is three-times that of cast iron and this combined with a greater thickness necessary for strength, enables an alluminium piston alloy to run at much lower temperatures than cast iron. As a result carbonised oil does not form on the underside of the piston and the crank case keeps always clean. SAE has recommended the following composition.

SAE 300 : Heat resistant aluminium alloy with the composition, Cu 5.5 to 7.5 %, Fe 1.5 %, Si 5.0 to 6.0 %, Mg 0.2 to 0.6 %, Zn 0.8 %, Ti 0.2 %, other Elements 0.8 %.

Advantages:

Maintain mechanical properties at elevated temperature,Heat conductivity about 4.4 times cast iron, Specific gravity 2.89

SAE 321 : Low expansion Alloy having the composition, Cu 0.5 to 1.5 %, Fe 1.3 %, Si 11 to 13 %, Mn 0.1 %, Mg 0.7 to 1.3 %, Zn 0.1 %, Ti 0.2 %, Ni 2 to 3 %, other Elements 0.05 %.

Y – Alloy: (Developed by National Physical Laboratory, London.) it is also called alluminium alloy 2285. This alloy is noted for its strength at elevated temperatures.

Also used for cylinder heads. Composition of Cu 4%, Ni 2%, and Mg 1.5%

RESULTS AND DISCUSSION

Based on the strength of material

Thickness of piston head based on the strength of piston material $t_1 = (\sigma_p)^{1/2} D \cdot (16S_{tp})^{1/2}$

$S_{tp} = 50$ to 90 N/mm^2 for aluminium alloy

$S_{tp} = 35$ to 40 N/mm^2 for C.I

$S_{tp} = 60$ to 100 N/mm^2 for steel

$t_1 = (\sigma \cdot 0.567)^{2/3} 80 / (16S_{tp})^2 = 3.367 \text{ mm}$

Thickness of piston head due to heat dissipation = $1000 \cdot H / 12.56 k (T_c - T_e)$

$H = 0.05 \text{ m} \cdot C_v \cdot P_B \text{ KW}$

$C_v = 44 \cdot 10^3 \text{ KJ/Kg}$ for diesel fuel

$P_B = p_m L A n / 60 \cdot 1000 \cdot 1000 \text{ kw}$

$k = 175 \cdot 10^{-3} \text{ kW/m}^0\text{C}$

$T_c - T_e = 75^0\text{C}$ for aluminium alloy

$L = 106.096$

$A = 5026.55 \quad [\sigma r^2]$

$n = 400$ for 800 r.p.m

$P_B = 0.888 \text{ kws}$

Thickness of piston head due to heat dissipation = $1000 \cdot 1953.6 / 12.56 \cdot 175 \cdot 10^{-3} (75) = 11.85 \text{ mm}$

MATERIAL PROPERTY

The piston is made up of casted aluminium alloy. The material property of the piston assumed in the analysis is shown in table.

Table 1

SL.NO.	PARAMETER	VALUE	UNIT
1	Young's modulus	0.7x105	Mpa
2	Poisson Ratio	0.35	-
3	Density	2700	Kg/m3

Table 2

Piston diameter (D = 80 mm)

DESCRIPTION	DIESEL ENGINE
Crown thickness, σ	$(0.20-0.12) \cdot D = 12.8 \text{ mm}$
Piston height, H	$(1.7-1.0) \cdot D = 108 \text{ mm}$
Height of top part, h_1	$(1.0-0.6) \cdot D = 104 \text{ mm}$
Skirt height, h_s	$(1.1-0.6) \cdot D = 68 \text{ mm}$
Thickness of skirt wall, σ_s	$(5.0-2.0) = 3.5 \text{ mm}$

Thickness of crown wall, s	$(0.1-0.05)*D = 6 \text{ mm}$
Thickness of first land h_1	$(0.07-0.04)*D = 4.4 \text{ mm}$
Distance of the first ring groove, h	$(0.20-0.11)*D = 12.4 \text{ mm}$
Radial thickness of ring, t_r	$(0.045-0.040)*D = 3.4 \text{ mm}$
Piston ring depth, a	4= mm
Difference between the free gap and compressed gap of ring, A_0	$(4.0-3.2)t_r = 12.24 \text{ mm}$
Radial clearance of ring in piston, Δt_r	
For compression ring	$(0.95-0.7) = 0.825 \text{ mm}$
For oil control ring	$(1.1-0.9) = 1 \text{ mm}$
Piston inner dia, D_i	$D-2 (s + t_r + \Delta t_r)$
Compression ring	$80-2 (4+0.4+0.825) = 63.55 \text{ mm}$
Oil control ring	$80-2 (4+0.4+1) = 63.2 \text{ mm}$
Number of oil holes, n	9
Oil hole diameter, d_0	$(0.5-0.3)* = 1.6 \text{ mm}$
Pin outer dia, d_p	$(0.38-0.3)*D = 27.2 \text{ mm}$
Pin inner dia, d_i	$(0.7-0.5)* d_p = 16.32 \text{ mm}$
Pin length, l_p	
For retained pin	$(0.93-0.88)*D = 72.4 \text{ mm}$
For floating pin	$(0.9-0.8)*D = 68 \text{ mm}$
Connecting rod bushing leangth, l_c, r	
For retained pin	$(0.32-0.28)*D = 24\text{mm}$
For floating pin	$(0.45-0.33)*D = 31.2 \text{ mm}$

Following are the sequences of steps in which the piston is modelled:

Firstly Key points are generated. A straight line is drawn through Key points to form a half portion of the piston. Fillets are applied at corners. Area command is applied to generate half area of the piston. Extrude command is applied to generate volume of the piston. Finally, the hole is created.

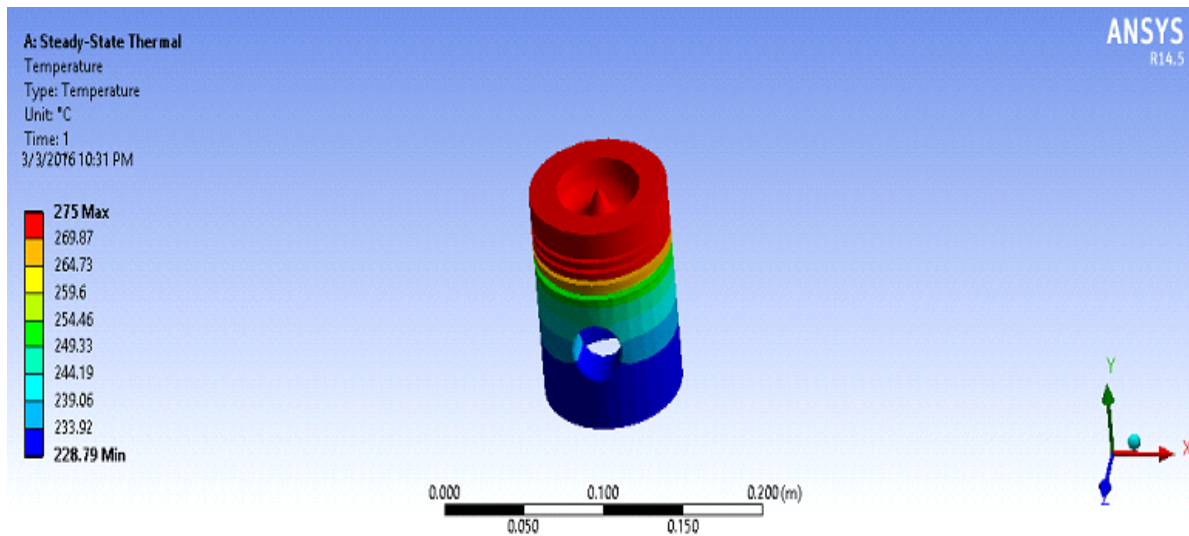


Fig 1 -Temperature Distribution for TCC

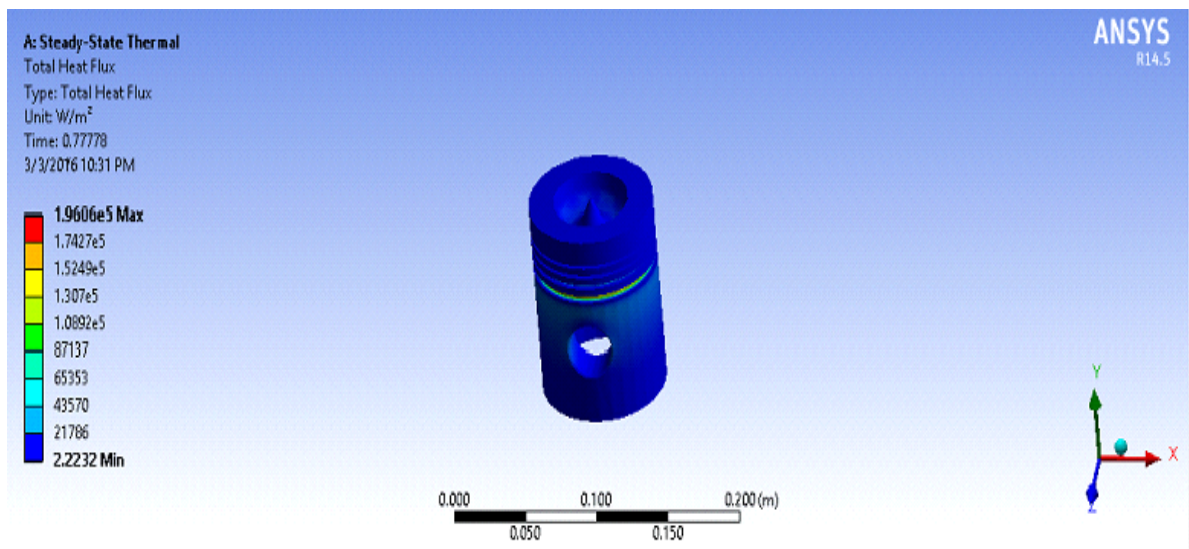


Fig 2 -Total Heat Flux for TCC

CONCLUSION

1. The geometry of the piston is modified by Toroidal bowl piston to induce turbulence charge in the combustion chamber.
2. By observing the above analysis results of we can conclude that using aluminium alloy for both connecting rod and piston is more beneficial than using steel for piston.

3. While comparing stresses of the modified assembly is having less stresses than previous assembly.
4. Displacement and strains are negligible. By changing the piston and connecting rod material we can reduce the load effect on crank shaft. So that crankshaft life will be extended.
5. Aluminium is having very less weight comparing to the steel so that we can conclude that modified assembly is having more mechanical efficiency and also we can reduce the cost of the product and production (Aluminium products are manufactured in cold chamber castings).

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