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A Toroidal Piston Design and Analysis Using Ansys

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Abstract

Ansys software was used to create a toroidal piston bowl. In this paper, the temperature distribution and total heat flux are provided. We begin by presenting studies on Toroidal piston and related topics by various writers. We conduct a detailed analytical examination of a Toroidal Piston utilising the Ansys programme by giving our own experiment and results later in this article.

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

INTRODUCTION

Around the year 1920, cast iron pistons were replaced with aluminium alloy pistons (Sarkar 1975). According to Cole G.S. and Sherman A.M. (1995), there has been a growing interest in substituting cast iron and steel in automobile components such as pistons with light weight aluminium alloy casting to increase performance and efficiency. The low expansion group of aluminium–silicon alloy is referred to as piston alloy by Haque M.M. and Young J.M. (2001), since it provides the best overall balance of attributes. Due to their multicomponent microstructure, near eutectic aluminium silicon piston alloys have complicated fatigue behaviour (Moffat et al 2005). All basic casting procedures may be used to cast aluminium alloys (Budinski 2001). A metal-based insert is reinforced with the base alloy to increase wear performance. During the casting process, cast iron and steel inserts are usually strengthened with a light weight alloy. Special proprietary procedures are employed to produce the bonding of aluminium and cast iron. Dirt and oxide cause problems with the bonding between the implant and the alloy. Before casting, the component was coated with a tin layer by dipping or electro plating, followed by heat treatments (Cole and Andrew T 1991). The Al-Fin process employs both gravity die casting and pressure casting techniques. In the gravity die casting and squeeze casting methods, a specific casting technique developed from the so-called Al-Fin process is employed. The Al-Fin (also known as Al-Fer) technique creates a diffusion connection between the insert and the aluminium alloy. At the reinforcement area, liquid aluminium reacts aggressively with iron, forming brittle intermetallic compounds. Diffusion of reactive species via the intermetallic layer, not the interfacial chemical interaction, limits the rate of expansion of the intermetallic layer (Vaillant Ph and Petitet J.P. 1995). However, the light alloy's poor hardness and greater service temperature during piston operation offer certain challenges (Snee 1985).

A piston is created by pressing aluminium or aluminium alloy into a porous layer with a thickness of 20 to 50 times the pore diameter and entirely filled with the piston body metal that extends from the body into the pores of the insert. In the high load bearing zone of an aluminium alloy, steel and cast iron are commonly employed as reinforcement. A porous ceramic insert can also be utilised as reinforcement to increase performance. The pores of the ceramic insert are filled with liquid aluminium alloy during the squeeze casting process (Kohnert 1982). The hot dipping procedure was created to create a strong connection between ferrous metals and liquid aluminium alloys. Coat the steel insert with a thin coating of aluminium to increase its wettability and bonding. Grey cast iron is used as an insert material because of its exceptional workability, high heat conductivity, and good wear resistance (Birigt Hudelmair 2000). According to Morishita (1981), pistons made of aluminum-based alloy are used in internal combustion engines, particularly diesel cycle engines, to improve heat radiation and reduce weight. Casting the aluminium alloy around the insert body can solve this problem. The dipping duration of the insert was changed from 3 to 7 minutes for improved adherence. Copper-based alloy was used to fill the pores of the sintered austenitic ferrous alloy body, proving the insert's density.

Durrant G. et al. (1996) described the squeeze cast process for reinforcing an aluminium alloy with a mild steel insert.

The bonding of the aluminium silicon alloy with the reinforced insert is critical in extending the component's service life. Surface impurities and surface oxides limit the necessity of a proper registry between these reinforced inserts and alloys (Stefaniay et al 1987). Squeeze casing approach enhances the bonding strength of an aluminium alloy casting with a porous metal insert. To optimise packing, the porous insert might be preheated before the casting process (Takasuga 1990). The electro plating process, as discussed by Han and More K.L., can also be used to cover the insert (2003). In metal die cast goods, a stamped steel insert is utilised as an insert. The insert consists of two linked stamped steel insert pieces that are spaced apart at particular points to form a void. To avoid bimetallic machining, the insert's edges are positioned below the casting's surface. This is, however, still in its early phases of development (Shimmell 1998). Donomoto (1985) described a method for strengthening porous materials. It is heated to a temperature that is significantly higher than the melting point of the matrix metal. The molten matrix metal is then injected under high pressure into the porous structure of the reinforcing material. Then, while maintaining the above-mentioned significant pressure, the combination of the reinforcing material and the matrix metal infiltrated there is cooled to a temperature below the melting point of the matrix metal.

The head section of the piston is fitted with a ceramic insert that is mechanically locked to it. Pores are present on the ceramic insert, at least on the section that engages the piston head. The pores have diameters that allow them to be filled with light alloy during the squeeze casting procedure used to make the piston (Mahrus 1988). Pistons are made up of two pieces. The primary section of the piston is made of gravity die cast aluminium or aluminium alloy, and the second half is made of a squeeze casting method that produces a material that is stronger and more resistant than gravity die cast aluminium or aluminium alloy. To finish the piston, the two pieces are then electron beam fused together. To increase the qualities of the squeeze cast, it might be reinforced with whiskers or fibres. This technique of manufacture has the advantage of requiring the more expensive and time-consuming squeeze casting process for only a tiny piece of the piston. In huge diesel pistons, this is an advantage (Avezou 1987). David J. (1985) focused on developing a wear-resistant inlay for light-weight alloy pistons. An circular ring of wear-resistant material with a cylindrical outer edge makes up the insert. At least one projection or tab extends outward from the peripheral edge of the annular ring for placing and maintaining the annular ring in a die cavity during the casting process. In light metal castings for use in internal combustion engines, ceramic inserts are placed in thermally loaded zones as heat insulation. A metallic substance that resists creep and relaxation is shrunk on the insert before it is inserted to establish a solid junction between the insert and the light metal (Sander 1985). The fabrication of a reinforcement component that does not have to be exactly in the shape of a disc and can be of any convenient shape is required for the strengthening of the crown of an aluminium or aluminium alloy piston for an internal combustion engine (Graham 1986). The presence of brittle intermetallic phases at the contact reduces the component's life. Vibration aided casting and heat treatment are two approaches that can help solve such challenges. Such procedures are required in the piston industry (Dwivedi et al 2007).

Budinski went over the typical heat treatment cycles for aluminium alloys in great detail (2001). Precipitation hardening strengthens all treatable alloys (Mike Meier 2004). Solution heat treatment and quenching, followed by a precipitation treatment, were used to improve the piston's mechanical characteristics (Cole and Andrew T 1991). Solution, ageing, and precipitation heat treatments can enhance the wear performance of piston alloy, according to Durrant G. et al (1996). During the contact of solid metal with liquid, Yeremenko et al (1981) discovered the creation of a brittle layered intermetallic phase. Many studies have been published on the ternary (Al-Fe-Si) chemical system. The phase diagram can be used to identify ternary compounds (Ragavan 2002). FeAl2, Fe2Al3, and FeAl3 are three intermediary phases in the system with constrained homogeneity ranges.

To attain the correct size and surface quality, machining is required. The metal cutting industries continue to be plagued by the problem of not operating machine tools to their full potential (Hari Singh and Pradeepkumar 2005). H.K. Tonshoff, H.K. Tonshoff, H.K. Tonshoff, H.K. Tonshoff, H.K. Tonshoff, H.K. Tonshoff, H. K. Tonshoff, H.K. Tonshoff, H.K. Tonshoff, H.K. Tonshoff, H.K. Tonshoff, H.K. Tonshoff, H.K. Ton Hessman Ingemar (2005) disclosed that cemented carbide cutting tools may be used to process bimetallic components in his patent.

Coated cemented carbide cutting tool inserts are used for bimetal machining of engine blocks made of cast iron and aluminium alloys under wet conditions at a moderate cutting speed. Bimetallic bodies are machined at a moderate cutting speed using a cemented carbide cutting tool, resulting in poorer productivity. The development of environmentally friendly and cost-effective cutting technologies, including high-performance tool materials appropriate for dry speed cutting, is in great demand today (Hovsepian et al 2005).

Zone Ching Lin and Din Yan Chen (1995) investigated Cubic Boron Nitride (CBN), a sintered material that may be employed as a cutting tool material for hard turning and increased productivity. CBN tools have a number of advantages, including long wear life, high hardness, and superior temperature resistance. The tool is exceedingly expensive, costing 10-20 times more than carbide tools (Steven Y Liang 2003). The better productivity and enhanced quality of the machined surface compensate for the high initial cost of these CBN tools. In some cases, precision finish turning might be used instead of grinding. According to Kivilcim Buyukhatipoglu (2003), due to recent advancements in cutting tools and machine tool structural stiffness, hard turning offers a cost-effective and time-saving alternative to various grinding processes. CBN tools with a high percentage of CBN (90%) produce a higher surface finish (Radu Pavel 2004). The role of cut geometry in determining the life time of a CBN tool is discussed by Mehdi Remadna and Jean Francois Rigal (2006). If a tool has coarse grain size, high abrasion resistance is necessary for better performance (Ding.X et al 2005).

Previously, two distinct tools and two different cutting settings were utilised to machine bimetallic components. The cycle time has risen as a result of the frequent tool changes. As a result, a single tool for cutting both metals is required. There is currently a scarcity of literature on the machining and surface integrity of such bimetallic components. This research attempted to overcome such issues in bimetallic component machining.

Because of the continual increase in product quality, Taguchi's quality design, initially developed in the 1960s, is extensively used (Chih Wei chang and chun pao kuo 2006). Through the introduction of Dr. G. Taguchi's concepts, the use of planned experiments in manufacturing and engineering design contexts has grown increasingly common in recent years (Henry S. Lewandowski 1989). The robust design approach based on the Taguchi technique has resulted in a unique and effective quality improvement discipline that varies from typical processes (Roy R. 1990). The method of matrix experiments is used in robust design. The experimental matrix is a particular orthogonal array that enables for the efficient study of the simultaneous effects of numerous process factors. The life cycle, cost, and quality of a product or process are all influenced by its design (Tapan P. Bagchi 1993). The number of degrees of freedom is calculated by multiplying the number of parameters and their levels of variation by the number of degrees of freedom. To calculate cutting parameters and discover the key characteristics impacting the turning process while considering tool life and surface roughness, Yang Y.H. and Tang (1998) employed orthogonal array for signal to noise ratio and analysis of variance. A research on the impact of cutting velocity, feed, and cutting time in turning metal matrix composites was given by Paulo davim and Antonio C.A. (2003). A neural network approach for surface roughness prediction was published by Benardos and Vosniakos (2002). Ultrasound is utilised to check the bonding region's quality (Mark willcox 2003). Ravindra H.V. et al. (1993) investigated tool wear in turning operations using cutting forces. Cutting pressures in metal cutting have a direct impact on heat generation, tool wear or failure, machined surface quality, and work piece precision (Suleman yaldu 2006). Cutting force analysis in fine turning is commonly linked to the hardness and strength of the work piece material under various machining settings (Grum and Kisin M 2003). The microstructure of a material can influence its hardness, strength, and machinability. The creation of a built-up edge and an adhesive coating are the major causes of tool wear (List et al 2005, Nouari et al 2003).

Cutting forces are primarily influenced by cutter geometry, work piece hardness, and feed (Li Qian and Mohammad Robiul Hossan 2007).

The wear on the tool face was determined by examining the crater caused by chip flow along the face (Geoffrey Boothroyd 2005). When milling medium hardness steel with a CBN tool, WuyiChen (2006) found that the radial thrust cutting force was the biggest of the three cutting force components and the most responsive to changes in cutting edge geometry and tool wear. The effect of rake angle on cutting force was discovered by Mustafa Gunay et al (2006). It has been proven that when the rake angle rises, the mean cutting force falls.

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 $t_1 = (\square\ p)^{1/2}$ $D*(16S_{tp})^{1/2}$

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 = (□ *0.567)^{2}80 / (16S_{tp})^2= 3.367 mm

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

H = 0.05 m * C_v * P_B KW

C_V = 44 * 10^3 KJ/Kg for diesel fuel

P_B = p_m LAn / 60*1000*1000 kw

k = 175 * 10^{-3} kW/m/^{0}C

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

L = 106.096

A = 5026.55 [□ r^2]

n = 400 for 800 r.p.m

P_B=0.888 kws

Thickness of piston head due to heat dissipation = 1000* 1953.6 /12.56 * 175 * 10^{-3} (75)= 11.85 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, □	(0.20-0.12)*D = 12.8 mm
Piston height, H	(1.7-1.0)*D = 108 mm
Height of top part, h_1	(1.0-0.6)*D = 104 mm
Skirt height , h_s	(1.1-0.6)*D =68 mm
Thickness of skirt wall, □$_s$	(5.0-2.0) =3.5 mm
Thickness of crown wall, s	(0.1-0.05)*D = 6 mm
Thickness of first land h_l	(0.07-0.04)*D =4.4 mm
Distance of the first ring groove, h	(0.20-0.11)*D =12.4 mm
Radial thickness of ring , t_r	(0.045-0.040)*D =3.4 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 mm
Radial clearance of ring in piston, Δt_r For compression ring For oil control ring	 (0.95-0.7) = 0.825 mm (1.1-0.9) = 1 mm
Piston inner dia, D_i Compression ring Oil control ring	D-2 (s + t_r + Δt_r) 80-2 (4+0.4+0.825) = 63.55 mm 80-2 (4+0.4+1) = 63.2 mm
Number of oil holes , n	9
Oil hole diameter, d_0	(0.5-0.3)* = 1.6 mm
Pin outer dia, d_p	(0.38-0.3)*D = 27.2 mm
Pin inner dia, d_i	(0.7-0.5)* d_p = 16.32 mm
Pin length, l_p For retained pin For floating pin	 (0.93-0.88)*D = 72.4 mm (0.9-0.8)*D = 68 mm
Connecting rod bushing leangth, l_c , r For retained pin For floating pin	 (0.32-0.28)*D = 24mm (0.45-0.33)*D = 31.2 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.

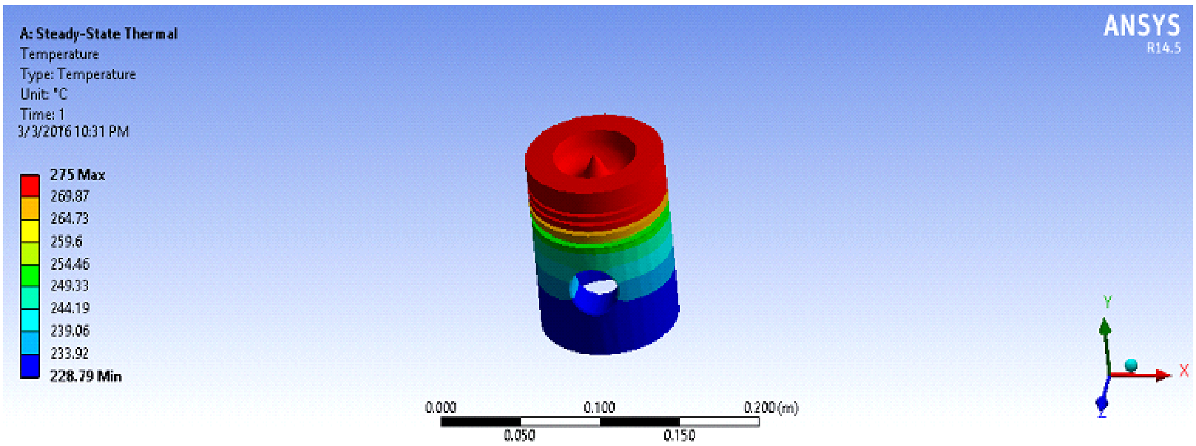

Fig 1 -Temperature Distribution for TCC

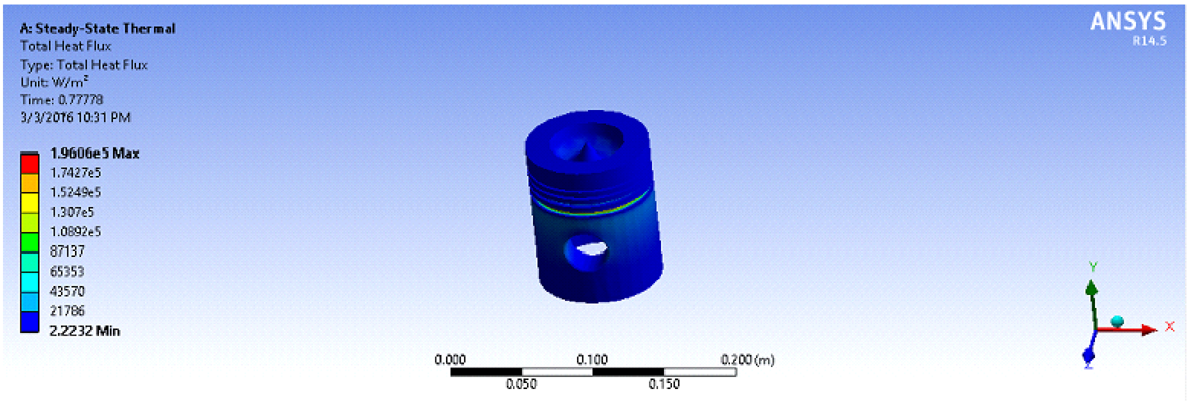

Fig 2 -Total Heat Flux for TCC

CONCLUSION

1. The geometry of the piston is modified by Toroidal bowl piston to induce turbulenc 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 forpiston.

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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