CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This work concentrates on processing and machining of bimetallic pistons. This chapter gives an insight for the thorough understanding of the state-of-art in

1. Bimetallic pistons
2. Heat treatment
3. Machining of bimetallic pistons and machinability studies

The work addresses the requirement of a piston industry. It emphasizes on the productivity improvement of the bimetallic pistons. Due to its industry relevant nature, the literature available for this topic is scarce. Albeit, some limited literature is available; most are patented.

2.2 LITERATURE SURVEY

The cast iron pistons were superseded by aluminum alloy piston around the year 1920 (Sarkar 1975).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 aluminum alloy casting to improve the performance and efficiency. Haque M.M and Young J.M. (2001) referred the low expansion group of aluminum–silicon alloy as piston alloy, since this group of alloy provides the best overall balance of properties. Near eutectic aluminum silicon piston alloy exhibit complex fatigue behavior due to their multi component microstructure.
Aluminum 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 aluminum 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 aluminum alloy. When the liquid aluminum 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 Petitet 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 aluminum or aluminum 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 aluminum 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 aluminum alloy (Kohnert 1982). To produce a good bond between ferrous metals and aluminum alloys liquid metal, hot dipping process was developed. To improve the wettability and bonding of the steel insert, first coat it with thin aluminum 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 aluminum based alloy is provided for the purpose of better heat radiation and lower weight. Such problem can be alleviated by casting the aluminum 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 aluminum alloy reinforced with mild steel insert by squeeze cast technique. The bonding of aluminum 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 aluminum 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 aluminum or aluminum 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 aluminum or aluminum 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 aluminum or aluminum 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 aluminum 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: FeAl₂, Fe₂Al₃, and FeAl₃.
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 aluminum. 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 (Suleyman Yaldi 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).

Wuyi Chen (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.

Palanikumar (2007) optimized the design for the formulation of mathematical model to predict tool wear in the machining of glass fibre reinforced composites. Axinte D.A et al (2000) created a model based on experiments in order to predict the cutting force during turning with uncertainty components. Functional or empirically developed mathematical models explicitly link a quantitative dependent variable to certain independent variables (Gaitonde V.N 2005). Kalyanmoy deb (2000) explained the Genetic Algorithm (GA), which is of computerized search and optimization algorithm based on the mechanics of neural genetics and natural selection. The quality is the fitness function which evaluates a chromosome with respect to the objective function of the optimization problem (Asokan and Saravanan R. 2001). The optimization based on GA has proved to be very useful in dealing with discrete variable defined on the population on cutting condition values from experiment (Paulo Davim 2001). David E Goldberg (2000) formed a class of evolutionary heuristics based on principle derived from the dynamics of natural genetics. Ibhadode (2004) proposed GA technique for optimizing parameter for various conditions. Hari singh (2005) reviewed the various traditional and non traditional optimization techniques implemented for the machining problem.

2.3 RESEARCH GAP

There is a continuous improvement for high strength to weight reduction for the piston. When light alloy is reinforced with wear resistant insert, the bonds between the reinforcement and matrix alloy do pose
problems. Suitable heat treatment techniques are necessary to enhance the service life of the component. As such, there is no relevant literature available on bimetallic machining. Hence, this research is proposed with the objective of identifying a suitable heat treatment and machining of such heat treated bimetallic pistons.

2.4 MOTIVATION FOR THIS WORK

During the industrial visits made by the author, the seed for this project is conceived. Currently Al-Fin, a patented process, is used for manufacturing pistons. To increase the bonding strength of aluminum alloy with the reinforcement, suitable heat treatments should be employed. Near net shape pistons are manufactured by machining and it needs two different tools, one for aluminum and another one for the cast iron. Hence, it is required to identify a suitable tool to machine both the metals to reduce the cycle time.

2.5 OBJECTIVES

After performing a detailed literature survey and industry visits, the following objectives are formulated for this research work:

- Manufacturing of bimetallic piston with different dipping time cast iron inserts.
- Performing different heat treatments to enhance the strength of bonding region and to implement a suitable process.
- Machining for both the metals with a single tool in order to reduce cycle time studies using Taguchi’s robust design.
- Evaluating the surface integrity of machined pistons by the way of measuring surface roughness and bond testing.
2.6 FUTURE SCOPE

- A thorough tool wear analysis can be attempted. So that one can establish the relationship between tool wear and surface roughness.
- Study on tool wear mechanism imparts an understanding about the bimetallic interaction with the CBN tool during machining.
- Coating on insert could be done by electro plating instead of dipping.
- More study should be done by changing the dimension or shape of the insert in order to have better bonding.