Operational requirements and service conditions of piston engineering essay

ABSTRACT

There is an extent in changing the trend of the material by its properties and its characteristic. The majority of the materials completely depend on the application of the material in the component and its versatility. The components by material vary from each other by its properties. The materials have the tendency to change its manufacturing process by its character. A component can be manufactured by using various materials depending according to the application and its life. In this paper we discussed about the manufacturing process of the components like piston, connecting rod and the crank shaft. The alternative methodologies and usage of alternative materials are also explained by using CES chart with its advantages.

INTRODUCTION

Selecting the appropriate material is an integral part of the successful implementation of an engineer's design. A design engineer's ability to objectively quantify the combined marketing, technical and manufacturing requirements as they apply to the material selection is critical to the actual as well as the perceived success of the product. This paper contains a deep knowledge about the selection of the material and its manufacturing procedure with justification.

CHAPTER 1 – GENERAL COMPONENT DETAILS

1. 1 PISTON

The piston is the most essential component of the engine which actually transfer the energy output from the combustion chamber to the crankshaft through connecting rod. This is a pressure-tight cylindrical plunger which is subjected to the expanding gas pressure. Basically, piston structural components are head, skirt, gudgeon pin, grooves and lands.

1. 1. 1 OPERATIONAL REQUIREMENTS AND SERVICE CONDITIONS OF PISTON

Hence in order to transmit this high power output the piston must be designed lightly and must be robust. The piston must be of higher strength material that can with stand the high pressure that is been generated due to the burning of air-fuel mixture within the cylinder. Piston must be fitted properly to control the expansion due to temperature, without which the piston will fit loosely when in cold and they bind themselves when it gets warmed.

1. 1. 2 FUNCTIONS OF PISTON

Transmit energy from combustion unit to piston pin,

Serve as a carrier for the piston ring which seals the compression in the cylinder,

Act as a guide for upper end of the connecting rod,

Withstand high temperature expansion

Despite the heat energy to the coolant.

piston. gif

Fig(1) – Piston Assembly

Conditions of piston at normally high speed, Piston moves from the top to bottom of the cylinder and vice versa with a acceleration of speed of around 50mph at midpoint and decelerates.

The piston is subjected to pressure of about 6. 8MPA.

The piston is subjected to temperature of about 315°C.[1]

1. 1. 3 DESIRABLE MATERIAL CHARACTERISTICS

The Piston materials must meet the following conditions, [2]

Low thermal expansions for arresting the hot gases.

High thermal conductivity for releasing heat from piston head.

High strength to mass ratio (light weight) for transmitting high power output.

High fatigue strength for increasing the material strength.

Good resistance to surface abrasion.

To reduce skirt and ring groove wear.

1. 2 CONNECTING ROD

Connecting rod is a part of the engine which connects the piston to the crankshaft. This connecting rod converts the linear motion of the piston to rotating motion to the crankshaft.

1. 2. 1 OPERATIONAL REQUIREMENTS AND SERVICE CONDITIONS []

Connecting rods should be made as long as possible to reduce the oblique angle by the cylinder axis.

Both tensile and compressive stresses are produced due to piston reciprocating-inertia loads.

In order to evade scuffing proper lubrication is needed. Lubrication of the small end by a hole drilled along the shank should be so arranged that the hole intersects the big end bore circumferentially.

To prevent buckling the rod shank is made in an ‘ H’ section, i. e., with a central web and two end flanges.

Intense heat is generated at high rotational speed, so large bearing area is required to make the rod wear well.

They should be checked for the correct length, weight distribution, straightness and freedom from twist.

1. 2. 2 FUNCTIONS OF CONNECTING ROD

As the word is self explanatory, the connecting rod connects the piston and the crankshaft.

The connecting rod continuously transmits energy from the combustion chamber to the crank shaft.

It actually converts the reciprocating motion of the piston to the rotary motion of the crankshaft.

These dynamic motions of the connecting rod makes it as light as possible whilst having a rigid section.

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1. 2. 3 DESIRABLES MATERIAL CONDITIONS

Must be strong to remain rigid under loading and light enough to reduce the inertia forces.

Material must have good elastic modulus.

It must have high fatigue strength in order to avoid failure due to high cycle fatigue.

Heat capacity of the connecting rod must be high.

Must withstand buckling stress due to large compressive loads.

Must be of low density to avoid bearing failure.

1. 3 CRANKSHAFT

Crankshaft is the central link-up for the power produced by each cylinder in the engine. This crankshaft is one of the heavier part of the engine which is to be made strong to withstand the load from the con-rod.

1. 3. 1 OPERATIONAL REQUIREMENTS AND SERVICE CONDITIONS

Fillet areas locations are to be verified since both torsional and bending loads are experienced during its service life.

Counterbalancing of weight is to be considered in order to counteract the centrifugal forces created by crankpin.

The projected areas of the big-end and main-end journals must be adequate to withstand maximum cylinder pressure.

After grounding should have a surface finish of 0. 5µm to minimize bearing wear.

Crankshaft must have the capacity to absorb the thrust loads from clutches or torque converter.

1. 3. 2 FUNCTIONS

It transmits power from combustion chamber to the flywheel through piston, piston rings and connecting rod.

It harness and phase the individual cylinder's power impulses transmitted through the mechanism of the connecting rod which converts the reciprocating motion of the piston to rotary motion at crankshaft.

It changes the linear displacement due to sudden shock caused by the combustion chamber into smooth rotary motion which is the input to many devices.

Crankshaft rotates in the cylinder in the cylinder block of the main bearing which supports the crankshaft which reduces the excessive wear.

http://www. motorera. com/dictionary/pics/c/crankshaft. gif

1. 3. 3 DESIRABLES MATERIAL CHARACTERISTICS

Material nominal stress must not exceed 20% of tensile strength in bending and 15% in torsion.

Must have the capacity to withstand large force from gas combustion.

Must have high heat withstanding capacity.

Must have low thermal expansion.

Must have high adequate strength, toughness, hardness, and high fatigue strength.

CHAPTER 2-MATERIAL SELECTION

2. 1 MATERIAL SELECTION FOR PISTON[hh]

Material selection process is an integral part of the overall product development process and must be considered in the early phases of the product definition. The material chosen for manufacturing the product is based on the following consideration,

Mass consideration

Strength and wear consideration

Heat-conduction consideration

Expansion consideration

Based on the above considerations the aluminium alloys satisfies all the factors comparing to cast iron and steel.

Mass consideration: Since the piston's reciprocating force is high at high speed, it is necessary to turn to light material instead of cast iron and steel. It has a relative density of 2. 6 when compared with 7. 8 for cast iron.

Strength and wear consideration: Since pure aluminium has low tensile strength of 92 to124 N/mm2 and fall of to 31N/mm2 at 300°C, it is always alloyed with copper or silicon for piston materials which improves the strength to mass ratio. At high level of silicon, the alloy exhibits excellent surface hardness, wear resistance properties and excellent dimensional stability.

Heat-conduction consideration: The better heat dissipation of aluminium-alloy pistons compared to cast-iron pistons greatly reduces the maximum piston-crown operating temperature of 250C – 300C for allou pistons and 400 to 500C for cast iron.

Expansion Consideration: The thermal expansion is less for Al-Si alloy which has a thermal expansin of 0. 000 021 and 0. 000 017 per °C for 12% Si alloy and 22% Si alloy.

Fig() CES chart

2. 1. 1 SURFACE CONSIDERATON:

Due to high speed reciprocation of the piston there may be so many losses or issues that must be considered. In that the frictional losses in piston assembly are majorly due to generation of heat. Subsequent raise in temperature can have this effect in the operation. In order to overcome this problem, proper material with good thermal conductivity is chosen.

2. 2 MATERIAL SELECTON FOR CON-ROD

The connecting rods are crucial and highly stressed component of the automotive engine subjected to alternative tensile and compressive stresses. Hence the material must be chosen based on the following conditions;

Good elastic modulus,

High fatigue strength,

Low density to avoid bearing failure and

High heat capacity.

Based on the following conditions microalloyed steel is chosen which meets all the requirements mentioned above. This steel has a hardness level of 20-30 HRC. Small microalloying additions of vanadium and niobium are used to increase the strength of carbon steel plates. 1. 1%Mn-0. 5%Cr is the best combination to obtain thee high fatigue strength. Lowering the carbon content down to 0. 33% and increasing the vanadium content to control the hardness gives toughness which improves the fatigue strength of free machining grades with S and Pb. The finally obtained chemical composition is 0. 33%C-1. 05%Mn-0. 5%Cr-0. 12%V-. 055%S-0. 20%Pb-Ca which has fatigue strength of 26% higher than a conventional microalloyed forging steel. As for connecting rod, application of light metal like titanium alloys and aluminium alloys are been tested, due to high cost in light metal the connecting rod are made of microalloyed steel. This structure contains ferrictic-pearlitic-bainit.

Fig() CES chart

2. 2. 1 SURFACE CONSIDERATION

The connecting rod is one of the highly stress concentrated part of the automotive engine. It is known that in the four cycle engines the connecting-rod small end is particularly stressed when the con-rod is at top dead centre at the beginning of the induction stroke, since the small end is ovalized by the tensile inertial forces exerted by the mass of the piston assembly. During both the stroke condition (expansion and compression) gudgeon pin pushes the small end along the lower end of the arc, by which the compression load directly acts on the con-rod without considerably stressing the eye. The eye is therefore subjected to repeated stresses, whereas the con-rod shank stress are reversed.(10)

2. 3 MATERIAL SELECTION FOR CRANKSHAFT (hh)

Crankshaft are from materials which can be readily shaped, machined and heat-treated and which have desirable mechanical properties such as adequate strength, toughness, hardness and high fatigue strength and of course , low cost. The highest quality steels are usually specified for satisfying the constraints given. Metals with optimum combination of bending and the stiffness are identified by creating a charts in CES by using performance indices in axes.

From the figure it is clear that the low carbon steel, high carbon steel, low alloy steel and medium carbon steel are satisfying the given constraints. Low alloy steel with chromium-molybdenum is used for crankshaft.

This forging steel is suitable for medium to heavy-duty petrol and diesel-engine crankshafts. It presents no difficulty in hot working and afterwards can be easily machined to size.

The alloying composition is 0. 4% carbon, 1. 2% chromium and 0. 3% molybdenum.

2. 3. 1 SURFACE CONSIDERATIONS

Since crankshaft is the most highly strained part of the engine with high load acting on it the following factors must be considered.

Pitting failure can occur in the crank-pin

Due to lack of surface integrity lack of control over stress and temperature.

CHAPTER 3 – MANUFACTURING PROCESS

3. 1 MANUFACTURING PROCESS FOR PISTON[SS]

Based on the material selected as aluminium alloys for piston, the manufacturing process is carried-out through casting because of its capability to produce near-net shaped parts at the required production rate. Hence the process selected for this component is the Gravity die casting.

3. 1. 1 GRAVITY DIE CASTING

The pistons are produced from high-silicon alloys, such as 413. 0 aluminium alloy. This alloy has high fluidity and can create high-definition surfaces through permanent mould casting; it also has high resistance to corrosion, good weldability, and low specific gravity. The universal acceptance of aluminium pistons for internal combustion engine applications is due to mainly to their light weight and high thermal conductivity.[ss] This type of casting is suitable for high volume production. The main advantages are the dimensional accuracy and surface finish. Castings ranging from few grams to 100kgs of aluminium alloy could be casted. This process could achieve higher mechanical properties than other casting by heat treatment. Since silicon has got good properties like, low shrinkage and imparting high fluidity which results in good casting. The maximum amount of silicon in cast alloy are in range of 22%-24%.(11)

Manufacturing route: [ss]

The h13 tool-steel mould is preheated to 200°C to 450°C, depending on the cast alloy and part size. Initially, the preheat is achieved with a hand-held torch, the mould reaches a steady-state temperature. Molten aluminium is heated to between 100°C-200°C above its liquidus temperature as shown below. Once the molten shot is in place the piston drives the mould in its place. Because of high thermal conductivity of the mould material, heat extraction from the molten metal is rapid and the metal solidifies in small channels before filling the mould completely.

[9]

3. 1. 2 MICROSTRUCTURAL CHANGES

Silicon has a diamond crystal structure and is consequently very brittle. These silicon structure damage the mechanical properties and nucleates on aluminium phosphide particles that is present in the melt as impurities. Further addition of sodium to the melt getters the phosphorous, which thereby increases the difficulty of sodium nucleation. Solidification is suppressed to lower temperature where the nucleation rate is large. This leads to remarkable refinement of microstructure. [9]

Aluminium

Silicon [9]

From the figure above the dark feature is a shrinkage pore caused by a casting defect. This figure shows the coarse silicon plates in an aluminium matrix.

3. 2 MANUFACTURING PROCESS

Microalloyed connecting-rod is manufactured by a simplified thermomechanical treatment like controlled cooling following hot forging. Through these processes desired properties could be obtained without quenching and tempering treatments. Hence powder forging was selected which would conveniently satisfy the manufacturing process for the selected material and component.

3. 2. 1 POWDER FORGING

Powder forging rods are manufactured by combining metal powders into a pre-form that is sintered and reheated to forging temperature. Then it is completely forged to its final shape and machined to its final dimensions.

This mixed powder is compacted at room temperature and high pressure upto to 200 to 400MPa. At the end of the process the powdered material acquires a density of 70 to 85%. This process has resulted in fully dense shape part which makes it suitable for high performance applications where high durability and strength are required. The detailed manufacturing route of this PF process is shown below:

[12]

The advantages of using PF process are,

Good dimensional accuracy

Minimum scattering of weight

Energy saving [12]

3. 2. 2 MICROSTRUCTURE [13]

[13pdf]

From the photograph of the microstructure of the connecting-rod material it is clear that the component contains pearlite and ferrite materials in composition. The above picture clearly indicates that in the powder metal connecting rods oxides are removed from the material surface by shot peening but the oxides are entrapped and remain below the surface causing the crack to originate below the surface

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3. 3 MANUFACTURING PROCESS

3. 3. 1 FORGING [ss]

The material selected for the crankshaft is forged steel which has a desirable mechanical properties such as adequate strength, toughness, hardness, and high fatigue strength. Hence the suitable manufacturing process for this steel is forging.

Forging is a basic process in which the work-piece is shaped by compressive forces applied through various dies and tooling. For this forging process the dimensional tolerance range from ±0. 5 to ±1% of the forging dimensions. At higher temperatures of about 700°C dynamic forging recrystallisation occurs which increases the stress and strain deformation of the metal to make it hard.

Manufacturing route:

Prepare a slug or billet

Heat the work-piece in the suitable furnace

For hot forging, preheat and lubricate the dies

Forge the billet in appropriate dies and in the proper sequence

Clean the forging and check its dimensions

Perform additional operations such as heat treatments and straightening

Inspect for defects

In the hot forging process to form a metal billet two or more dies are brought together to each other at a suitable room temperature in a shape of the die impression. This process follows two basic requirements,

The strength of the material must be low so that the die pressure can be kept within the limits.

The material should be capable of deforming without failure and should allow required amount of deformation.

The flow of metal and die filling are mainly determined by (i) flow stress and cooling ability

(ii) friction and cooling effects at the material interface. In this process, definite amount of heat is received by all the parts after machining in heat treatment process. This is mainly carried-out to improve fatigue and wear properties. High quality parts with moderate cost can be made by this process. Thus this process offers high strength to weight ratio, toughness and resistance to impact and fatigue to the material which is considered in the performance of the crank shaft. [14]

3. 3. 2 MICROSTRUCTURE

Heating above recrystallisation temperature causes recrystallisation that removes the microstructure deformed and generated recrystallised grains. After eutectoid-carburizing martensite transformation takes place and a black portion near the surface is formed consisting of fine grains of ferrite and carbide.

On quenching from the austentite (γ) phase martensite is formed. This transformation is a diffusion-less shear transformation .

Martensite is too brittle in plain carbon steel for practical applications and is subsequently tempered to restore some toughness.

CHAPTER 4 – ALTERNATE MATERIAL

4. 1 ALTERNATE MATERIAL FOR PISTON[hh]

Cast iron refers to the family of ferrous alloys composed of iron, carbon ranging from 2. 11% to about 4. 5% and silicon of about 3. 5%. They are classified by their structure ferritic, pearlitic, quenched and tempered or austempered. The equilibrium phase diagram relevant to cast iron is shown below where right boundary is 100%C. The eutectic temperature is 1154°C and thus cast irons are completely liquid at temperatures lower than those required for liquid steels.

One of the major disadvantage of the aluminium as the base metal of the piston is that it has high co-efficient of linear expansion in the range of 0. 0000221per°C, compared with 0. 0000117per°C of cast iron. Aluminium has twice the expansion rate of cast iron.

Cementite is metastable (not completely stable) which has a tremendously low decomposition rate. However it can be made decomposed into alpha-ferrite and graphite. The graphitization can be controlled, promoted and accelerated by adding silicon, controlling the rate of cooling and modifying the composition.[ss]

[15]

1. 4. 1 LIMITATIONS

Relative density is high of about 7. 8

When in tension, the presence of graphite acts as a stress riser weakens the material.

Strength properties of the cast iron are significantly affected by the shape and size of graphite.

Higher material and manufacturing cost.

The major disadvantage is the shrinkage.

1. 4. 2 POTENTIAL BENEFITS

Presence of graphite in cast iron improves wear-resistance as it acts as a lubricant.

High carbon content-degradation of ductility and fracture toughness.

Good corrosion-resistance.

Easy machinability

Wide range of composition and microstructures-easy weldability.

4. 2 ALTERNATE MATERIAL FOR CON-ROD

The alternate material chosen for connecting rod is aluminium alloyed material as it is light in weight and provides long service life to the part. The aluminium alloys are high strength-to-weight ratio, resistance to corrosion by many chemicals, high conductivity and ease of formability. The material composition of aluminium is 7. 6 to 8. 4% Zn, 1. 8-2. 3%Mg, 2-2. 6%Cu, 0. 08-0. 25%Zr, 0. 10%Si, 0. 15%Fe, 0. 05%Mn, 0. 04%Cr and 0. 06%Ti. When compared to othe alloys it convinces the constrains like low thermal expansion, wear-resistant, high fatigue strength and buckling.

Majorly this material is chosen based on the following consideration:

Mass consideration

Strength and wear consideration

Expansion consideration

Heat-conduction consideration

http://www. streetperformance. com/ART/PRODUCTS/100687/14012-8. jpg[19]

2. 4. 1 LIMITATIONS

It is more expensive than cast iron.

Low dimensional accuracy and poor surface finish.

Solidification is very slow.

Occurrence of fracture in short transverse direction.

Expansion rate is high when compared to cast iron with oure aluminium.

2. 4. 2 POTENTIAL BENEFITS

Aluminium alloys can be easily machined and welded and formed.

High dimensional accuracy with long service life.

High yield strength in both tensile and compression.

Aluminium is much better conductor of heat than cast iron.

Aluminium alloys provide improved resistance to abrasion and produce strength over temperature range.

Improves the performances of the piston and thus the engine.

4. 3 ALTERNATE MATERIAL FOR CRANKSHAFT

As the crankshaft is the heavier moving part in the automotive engine, the material selected for this part has to be strong and light. Titanium alloys having high strength with reduced weight is used for crankshaft until and unless cost is not considered, as this material is very expensive.

http://amt-advanced-materials-technology. com/s/cc_images/cache_867254901. jpg[17]

4. 3. 1 POTENTIAL BENEFITS OF TITANIUM ALLOYS

Titanium has high melting point of about1678°C which specifies strong creep and strength above wide temperature range.

The density is about 55% of steel with comparable strength.

Ti alloys exists in two allotropic forms α and β

Presence of thin oxide surface film-resistance over atmospher and sea environments including chlorine and organic chemicals.

Reacts rapidly with oxygen, nitrogen and constituents in cutting tools at high temperature.

4. 3. 2 LIMITATIONS

Embrittlement occurs during fabrication because of susceptibility of hydrogen, oxygen and nitrogen.

Forging with titanium alloys is expensive but it increases the strength of the material.

Ti alloys has a tendency to madden when tightening with connecting rod using bolt.

Titanium is more difficult to machine due its reactive nature.

Niobium

Titanium[16]

CHAPTER 5 – ALTERNATE MANUFACTURING PROCESS

5. 1 ALTERNATE MANUFACTURING PROCESS FOR PISTON

5. 1. 1 SAND CASTING

Sand casting is a one of the most feasible manufacturing process where the unit production is comparatively less. In this process a mixture of sand and clay is compacted around the pattern in which the pattern retains the shape of the original component to be produced. Then the pattern is removed in order have the cavity in the shape of the pattern. Generally low cost wooden patterns with gateways and runner are used. The molten metal is poured into the gateway by which it runs through the runner and fills the cavity and forms the exact shape of the cavity. Actually this whole system is housed in a box called flask. After which the molten metal allowed to solidify by cooling it. As the molten metal is solidified the sand pattern is broken and final work is done to obtain the finished component. The figure below shows the manufacturing process of the sand casting in detail.

http://openlearn. open. ac. uk/file. php/1689/T173_2_020i. jpg

Fig(8. 1) Sand Casting Process [18]

5. 1. 2ADVANTAGES

Low tooling and equipment cost

Component with any complicated shape can be produced

Relatively cheap process

Possibly components can be produced in large quantity.

5. 1. 3 DISADVANTAGES

High tolerance ratio is required

Labour cost is high.

5. 2 ALTERNATE MANUFACTURING PROCESS FOR CON-ROD

5. 2. 1 SQUEEZE DIE CASTING

Squeeze die casting or liquid metal casting involves the process of solidification of molten metal under high pressure. The machinery includes a die, punch and ejector-pin. Under the pressure applied by the punch keeps the entrapped gases in solution and the rapid heat transfer takes place at the die-metal contact which results in fine microstructure with good mechanical properties.[ss]

Elimination of shrinkage and gas porosity happens because of precise metal metering, quiescent die filling and high pressure.

5. 2. 2 ADVANTAGES

Precise dimension,

Excellent surface finish,

Fully shaped component is obtained

Complex part can be made to near-shape.

5. 2. 3 DISADVANTAGES

High initial cost

Limitation of high fluidity metals[20]

5. 3 ALTERNATE MANUFACTURING PROCESS FOR CRANKSHAFT

5. 3. 1 FORGING

In forging operations the metal is squeezed to shape by die in which the metal is subjected to large plastic deformation. These metals are placed in-between closed dies under high temperature and pressure which results in succession of the final shape.

http://www. forcast. ca/images/00436_faq1. gif[21]

Forgings generally are subjected to additional finishing operations, such as heat treating to modify properties and machining to obtain accurate final dimensions and surface finish.

5. 3. 2 ADVANTAGES

Good utilizations of materials

Good dimensional accuracy

High production rate

Good reproducibility

Low die costs

5. 3. 3 DISADVANTAGES

Initial cost is high

Not economical for small quantities

Machining often necessaries