Titanium and titanium alloys engineering essay

Material selection in manufacturing process is an important stage because proper selection of material not only can prevent catastrophic events from happening, but it allows a product to be manufactured in an efficient and effective way at low cost while meeting product performance objective. In this assignment, we are going to research into two material topics and identify the usage of these materials and overview some of the properties as to why they are chosen for specific application over the others and manufacturing processes.

Topic1: Titanium and Titanium Alloys

1. 1 Applications of Titanium Alloys

Titanium and its alloys are widely used in variety of areas. These areas include aerospace industry, marine operation, automobile, bio-medical applications, etc.

Figure 1: Applications of titanium alloy

1. 2 Automobile Connecting Rod

One application of titanium alloy is applied in producing connecting rod for automobile in order to achieve high performance for high end racing vehicle. Connecting rods are one of the most important automotive components as it responsible for changing the reciprocating motion of piston into rotary motion so that the power generated by the chemical energy can be transmitted from piston to crankshaft and finally producing forces driving the vehicle.

1. 3 Material Properties require for Connecting Rod

Weight is always an important factor to consider in racing sport competition, therefore in racing sport arena, car builders always try to reduce the overall weight of the vehicle so that every single drop of power generated by the engine can be utilized in providing motion for the vehicle rather than carry its own weight. This result in many of the car components are replaced by materials which are light, robust without compromising other materials properties like tensile strength, compression strength, damping capability, creep, fatigue, etc. This includes the connecting rod for the engine. The weight of the connecting rod is important because it influences the performance of the engine is terms of forces generated and response of the engine. If the connecting rod is made lighter, it is usually better as less weight enable the throttle action and acceleration can be carry out more smoothly and effectively, thus enhance the engine efficiency. However, strength and other aspect of materials properties are equally important owing to the reciprocating load generated by the movement of piston inside the cylinder and crankshaft. For every revolution of engine rotation, the connecting rod is under huge amount of compression and tensile forces. Hence, it is necessary that the connecting rods strong enough to handle all the power produced by the engine and withstand all the forces that tend to pull the rod apart during exhaust and crumble the rod during compression which results in irrepairable engine failure. Since the engine is operating at high temperature and needed to sustain a sudden force caused by the explosion of chemical happen within the cylinder, as a result it is very important that connecting rod possess high fatigue strength, high fracture toughness at elevated temperature, high shock resistance, etc. Summarizing

the needs for connecting rod, materials properties requires for a connecting rod include:

High strength to density ratio

Low density

Low thermal expansion

High fatigue strength in elevated temperature

High fracture toughness in elevated temperature

High shock resistance

Low ductile-to-brittle transition at low temperature

High melting point

1. 4 Manufacturing Processes of Connecting Rod

In general, connecting rods are produced by conventional forging method

Figure 2: Conventional Forging Manufacturing Processes for Connecting Rod

1. 5 Conventional Forging Method

1. 5. 1 Material

Titanium is extracted from titanium ore by Kroll Extraction process follow by blending, melting, casting, forming and heat treatment to produce the required material for connecting rod.

1. 5. 2 Cutting to length of material

The material is cut to the length near the final end product.

1. 5. 3 Billet Heating

Alloy is heated to make it malleable prior to forming operation.

1. 5. 4 Hot Forging

Red hot alloys which are in plastic condition are shaped into connecting rod by using compressive force. The alloys gone through the heating process is placed into die block and compressive force is imposed on the material by a hammer to strike it into the shape of connecting rod.

1. 5. 5 Trimming

After the forging process, the ledge of excess material is removed by trimmer machine.

1. 5. 6 Piercing

The material in the center of the holes is removed.

1. 5. 7 Shot Peening

Shot peening is used to produce a residue compressive force to modify the mechanical properties of the surface to further improve the fatigue resistance.

1. 5. 8 Machining

Machining process include deburring, milling, grinding, polishing, drilling, boring and inspection are carried out to produce the final connecting rod.

1. 6 Advantages and Disadvantages of Titanium Alloys

1. 6. 1 Advantages of Titanium Alloys

High strength-to-density ratio allows titanium alloy to replace steel and other materials in many areas.

Figure 3 and 4 reveals the superior structural efficiency of titanium alloys compared to other alloys, especially as service temperatures increase.

Figure 3: Structural Efficiency at Elevated Figure 4: Density Comparison for various

Temperature Metal

Specific Strength of Titanium Alloys is generally higher than any other alloy at elevated temperature.

Figure 5: Specific Strength for several alloy at elevated temperature

Titanium alloys have better fatigue strength than other lightweight alloys. For instance, aluminium, magnesium, etc.

The corrosion resistance of titanium alloys also far better than steel and even aluminium alloys. This enables titanium alloy product suitable to be used in caustic environment. The high reactivity of titanium with oxygen enable immediate forming of oxide layer which protect the material from corrosion.

The primary reasons why titanium alloys are attractive materials in many areas is because it exhibits excellent strength to density ratio, low density and corrosion resistance. Other aspect of material properties including the following:

High fatigue strength in air and chloride environments

High fracture toughness in air and chloride environments

Low modulus of elasticity

Low thermal expansion coefficient

High melting point

High intrinsic shock resistance

High ballistic resistance-to-density ratio

Nontoxic, non-allergenic and fully biocompatible

Excellent cryogenic properties

1. 6. 2 Disadvantages of Titanium Alloys

Titanium extraction process is difficult and expensive.

Titanium alloys have much higher flow stress than Al alloys or steels, thereby requiring much higher forging pressure capacity.

Titanium and its alloys are more difficult to machine especially beta phase titanium alloys in comparison with steels and aluminum alloys for conventional methods such as milling, turning, drilling, etc.

Titanium's has low thermal conductivity which reduces heat dissipation at the metal work-piece interface causing tool's lifetime reduce and decreased welding or galling at tool and work-piece interface.

1. 7 Structure and properties

Titanium alloys are classified according to the amount of alpha and beta resides in the structure at room temperature.

1. 7. 1 Alpha titanium alloy

The single phase alpha inhibits the heat treatment process. However it ensures weldability of the alloy. The strength and corrosion resistance at elevated temperature for alpha titanium alloys very much dependent upon the Aluminium and Oxygen element in the alloys.

Figure 6: Ti-5% Al-2. 5% Sn alloy in sheet form Figure 7: Commercially Pure Plate, 0. 03% iron

Air cool at 732C/30Min

1. 7. 2 Alpha beta titanium alloy

Beta stabilizing element results some beta phase to persist below the Beta Transus temperature which leading to two phase system. Two phase system enable Titanium alloy to be strengthened by heat treatment for example quenching, annealing, aging.

Figure 8: Titanium Phase Diagram Figure 9 : Ti-6AL-4V Alpha-beta alloy plate air cool at

788/15 min

1. 7. 3 Beta titanium alloy

Beta titanium alloys possess Body Center Cubic, BCC crystal structure is readily cold worked in the beta phase field. This allows solution heat treating follow by quenching giving high strength for the alloy.

Figure 10: Ti-13V-11Cr-3AL alloy solution heat Figure 11: Flow stress for Titanium alloys

treated at 788C/30min and water quenched

Topic 2: Ceramic Coating

2. 1 Ceramic Coating and Application

Ceramic coating is one of the coating techniques developed for spraying ceramic material on the surface of object of interest to further improve the mechanical and physical properties for a readily available product made from certain materials so that the component life can further be extended. The typical application of ceramic coating is applied to create the thermal barrier for gas turbine engine blade, exhaust system, intake manifold and reduces the surface friction between two different materials to improve the wear resistant as well as making the interface between two materials more compatible.

2. 2 Automobile Exhaust Manifold

Exhaust manifold serves as a system to vent the exhaust gases away from an engine so that new round of cycle can begin. In automobile, we always wanted the engine to perform work with as high efficiency as possible, however most of the conventional exhaust manifold is usually made from cast iron alloy and other material. These materials usually having good thermal conductivity. This is not preferable because high heat dissipation rate can contribute to loss of energy which reduce the efficiency of the engine. With ceramic thermal coating applied on the exhaust system, engine performance improves in a number of ways. Firstly, they protect the exhaust system from rust and corrosion. Secondly, they reduce heat loss which can be translated into engine output. This can be viewed from several aspects. Ceramic coating insulates the heat of exhaust gases from the environment

thereby keeping the exhaust gases hot which allow the gases flow more smoothly and these aids in cylinder scavenging. Next, by retaining the hot exhaust gases in the system, it reduces the engine bay temperature which results in intake air temperature reduced. Drop in intake air temperature can lead to less fuel usage and therefore increase the engine efficiency. For vehicle with turbocharger installed, the hot exhaust gases allow the turbocharger spool up more quickly making the engine more responsive.

2. 3 Processes for Ceramic Coating

2. 3. 1. Surface Cleaning

Before the manifold surface receive the ceramic coating, degreasing chemical would be used or material would be heated to high temperature to remove or burn off any foreign particle exist on the surface. The manifold will then be place in the oven at around 450 for around half an hour.

2. 3. 2 Coating

Ceramic coatings are mainly manufactured by using atmospheric plasma spray method, APS. APS using the strong electric arc that generated between a positively charged electrode and negatively charged electrode to ionize the flowing gases into plasma state, then followed by injecting powdered ceramic into the plasma jet in order to melt the powder materials and propelling them onto the work-piece surface. This process allows the metal substrate to be coated with ceramic leaving a smooth protective layer.

Figure 14: Atmospheric Plasma Spray Coating Technique

2. 3. 3 Finishing

The manifold is then allowed to air dry for around 20 minutes before placing it in the oven to set the coating. Once it has bakes, the manifold is polished with a steel wool brush.

2. 4 Advantages and Disadvantages of Ceramic Coating

2. 4. 1 Advantages of Ceramic Coating

Ceramic coating protect the metal surface against rust and corrosion which extends the component's life

Ceramic coating create thermal barrier which reduces heat lost which enhance the engine performance and reduces the engine bay temperature.

Ceramic coating can sustain high temperature up to 1100 which make it suitable for high heat application in aerospace as well as automobile industry.

Ceramic coating can survive bending and shock without crack, peel or forming chip

Ceramic coating comes in a variety range of colour which in turn improves the aesthetic for the component.

Ceramic coating can be removed easily

2. 4. 2 Disadvantages of ceramic coating

ceramic coating can be a costly process

uniformity of coating thickness can be quite difficult to maintain

might be difficult to apply to complex shape component owing to inside corned can have low film thickness according to " Faraday Cage Effect"

2. 5 Microstructure of ceramic coating by Atmospheric Plasma Spray, APS

Figure 15: (a) & (b) Microstructure of ceramic from literature

(c) Ceramic microstructure with thichness measured.