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Shot Peening & Fatigue Analysis

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1. Abstract

1.1 Fatigue:-

In materials science, fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values are less than the ultimate tensile stress limit, and may be below the yield stress limit of the material. Fatigue occurs when a material is subjected to repeat loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, persistent slip bands (PSBs), and grain interfaces. Eventually a crack will reach a critical size, and the structure will suddenly fracture. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets are therefore important to increase the fatigue strength of the structure. [1]

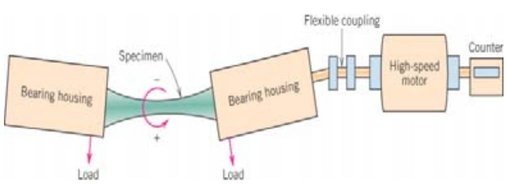

Fig1.1): Fatigue testing apparatus for rotating bending test.

1.2 Fatigue mechanism:

1.2.1 Fatigue Analysis:

i) Fatigue is a type of failure occurring under altering loads.

ii) Fatigue life is the number of cycling stresses, causing failure of the material.

iii) Fatigue limit is the maximum value of repeatedly applied stress that the material can withstand after an infinite no. of cycles.

The following Factors that affect fatigue-life:

- **Cyclic stress state:** Depending on the complexity of the geometry and the loading, one or more properties of the stress state need to be considered, such as stress amplitude, mean stress, biaxiality, in-phase or out-of-phase shear stress, and load sequence,
- **Geometry:** Notches and variation in cross section throughout a part lead to stress concentrations where fatigue cracks initiate.
- **Surface quality:** Surface roughness cause microscopic stress concentrations that lower the fatigue strength. Compressive residual stresses can be introduced in the surface by e.g. shot peening to increase fatigue life
- **Residual stresses:** Welding, cutting, casting, and other manufacturing processes involving heat or deformation can produce high levels of tensile residual stress, which decreases the fatigue strength.
- **Size and distribution of internal defects:** Casting defects such as gas porosity, non-metallic inclusions and shrinkage voids can significantly reduce fatigue strength.
- **Direction of loading:** For non-isotropic materials, fatigue strength depends on the direction of the principal stress.

1.2.2 Characteristics of Fatigue:

i) In metals and alloys, the process starts with dislocation movements, eventually forming persistent slip bands that nucleate short cracks.

ii) Fatigue is a stochastic process, often showing considerable scatter even in controlled environments.

iii) The greater the applied stress range, the shorter the life.

iv) Fatigue life scatter tends to increase for longer fatigue lives.

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v) Damage is cumulative. Materials do not recover when rested.

vi) Fatigue life is influenced by a variety of factors, such as temperature, surface finish, microstructure, presence of oxidizing or inert chemicals, residual stresses, contact (fretting), etc.

vii) Some materials (e.g., some steel and titanium alloys) exhibit a theoretical fatigue limit below which continued loading does not lead to structural failure.

viii) In recent years, researchers (see, for example, the work of Bathias, Murakami, and Stanzl-Tschegg) have found that failures occur below the theoretical fatigue limit at very high fatigue lives (10^9 to 10^{10} cycles). An ultrasonic resonance technique is used in these experiments with frequencies around 10–20 kHz.

2. Shot peening:-

2.1 Introduction

Shot peening is a cold work process, in which the metal part is struck by a stream of small hard spheres (shot) creating numerous overlapped dimples on the part surface. The surface material resists to stretching induced by the shots impacts resulting in a formation of a compression stressed skin of about 0.01” (0.25 mm) thickness. Glass, steel or ceramic balls of a diameter from the range 0.007-0.14” (0.18-0.36 mm) are used as shot media. The residual compression stresses inhibits both crack initiation and propagation. Therefore shot peening is used mainly for increasing strength. Dimples formed on a part surface as a result of shot peening may serve as lubricant “pockets”, which provide continuous lubrication of the part preventing galling. Steels, nodular (ductile) cast irons, Aluminum alloys, Nickel alloys and Titanium alloys may be treated by shot peening. Shot peening allows metal parts to accept higher loads or to endure a longer fatigue life in service without failure. In usual applications shot peening can be done without changing the part design or its material. [1]

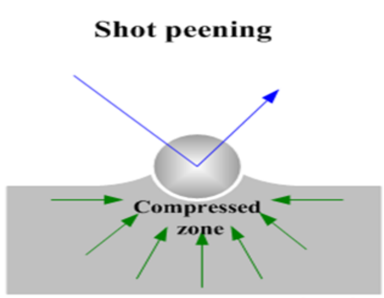

Fig: 2.1.1.Shot peening & compressed zone

Fig: 2.1.2.Shot peening for longer fatigue life

2.2 Effect of Shot peening:-

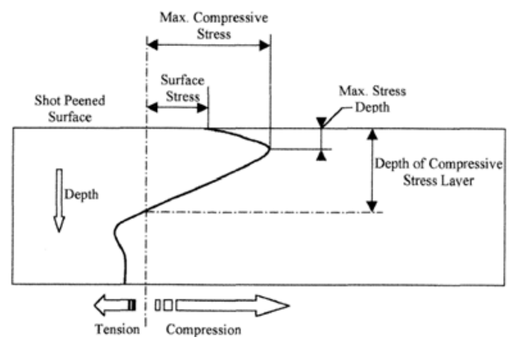

Fig: 2.2. Effect of shot peening

Its depth is largely dependent on the peening intensity and the relative hardness of the impinging shot and target material. For a relatively soft target material it is feasible to produce a compressive layer of 800 to 1000 µm deep, while for a harder material, it can be difficult to produce a compressive layer of much more than 200 to 250 µm. If the resultant surface stress can be made compressive enough, cracks could virtually be prevented from opening up at the component surface resulting in a much enhanced Fatigue life. This is generally true for shot-peened components subjected to low stress amplitudes.

2.3 Shot peening and Fatigue life:-

Shot peening is a cold work process that induces a protective layer of compressive residual stress at the surface of components. The objective of that compressive layer is to offset the applied stress, resulting in a benefit in terms of fatigue, corrosion-fatigue and fretting fatigue. In order to produce plastic deformation, a stream of metal, glass or silica particles (“shot”) is animated at high velocity and projected against the surface of the metallic component in a defined and controlled way. It is a study of the increase in fatigue life that it is possible to achieve

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with an appropriate use of shot peening. Some of these examples are: leafs spring - 600% increase; helicoidal springs - 1300%; gears - 1500%. These are some impressive examples how much life improvement is possible with shot peening. The main importance of shot peening is because it acts at the surface of components reducing the effective stress due to the compressive layer. This layer is only of some hundreds of microns depth, but enough to be quite effective. Some improvement is also attributed to the strain hardening due to plastic work at surface. However it is also necessary to account for the increase of surface roughness which has a negative contribute to the fatigue improvement. Normally it is assumed that contribute due to strain hardening is balanced by the increase in surface roughness. The Surface characteristics, the nucleation of fatigue crack generally occurs at the surface because this is the layer experiencing greatest stresses owing to presence of micro-notches, surface flaws, changed physical and chemical properties etc. delayed or prevented.

3. Shot peening on piston

3.1 Why piston:-

Piston is one of the critically loaded components in engine. Fatigue is a source of piston damages. Although, traditionally, piston damages are attributed to wear and lubrication sources, fatigue is responsible for a significant number of piston damages. Fatigue exists when cyclic stresses/deformations occur in an area on a component. The cyclic stresses/ deformations have mainly two origins: load and temperature. High temperature fatigue (which includes creep) is also present in some damaged pistons. Also thermal mechanical fatigue is present in other damaged pistons.

Shot peening is one of the process to enhance fatigue life of components & there is scope in study effect of shot peening on fatigue life of piston.

3.2 Objectives:-

1. To understand fatigue mechanism.
2. Study the phenomenon of shot peening & fatigue life.
3. Study of impact of shot peening on fatigue life.
4. Development of FE model to predict residual stress profile.
5. To study impact on fatigue life of piston due to shot peening.
6. To study of fatigue analysis by considering residual stress (prestress).

3.2.1 Impact of Shot peening on Fatigue life:

Shot peening is a cold working process that imparts a small indentation on the surface of a part by impacting small spheres called shot onto the material surface. This process creates the same effect that a peening hammer does by causing outer surface to yield in tension. The material directly beneath it is subjected to high compressive forces from the deformation and tries to restore the outer surface to its original shape. By overlapping the surface indentations, a uniform compressive layer is achieved at the surface of the material. The compressive layer squeezes the grain boundaries of the surface material together and significantly delays the initiation of fatigue cracking. As a result, the fatigue life of the part can be greatly increased. Shot peening process for increasing the fatigue life of various components subjected to fatigue stress. Shot peening is just one of the applications of shot blasting for increasing the fatigue life of various components subject to fatigue stress.

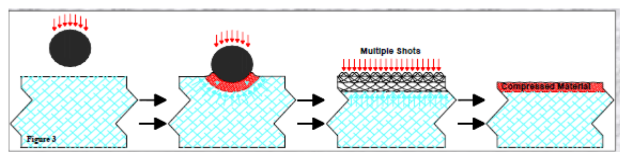

Fig: 3.2.1.1. Impact of shot peening on fatigue life

The cross-sectional area, A, increases with distance from the gun according to the equation From above fig:

We know that,

$$A = \pi R^2$$

But, $(\tan\alpha = R\text{-}r/D)$

$$R = r + D.\tan\alpha$$

So that,

$$A = \pi(r + D.\tan\alpha)^2$$

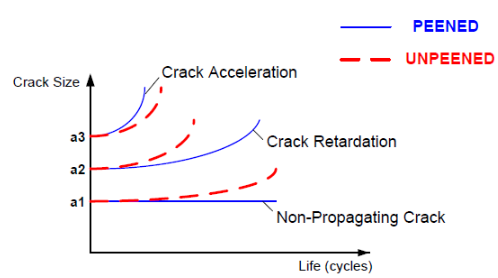

Fig: 3.2.1.2. Effect of shot peening on propagation behaviour of surface cracks.

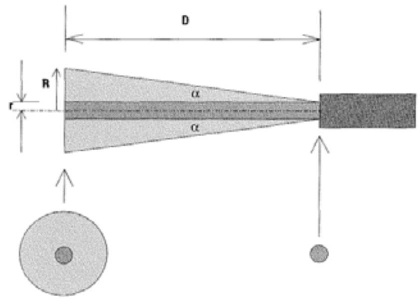

Fig: 3.2.1.3: - Geometry of shot stream divergence.

3.2.2 Methods of shot peening:-

i) Conventional (Mechanical) Shot Peening – Conventional shot peening is done by two methods. Method one involves accelerating shot material with compressed air. Shot is introduced into a high velocity air stream that accelerates the shot to speeds of up to 250 ft/s. The second method involves accelerating the shot with a wheel. The shot gets dropped onto the middle of the wheel and accelerates to the outer edge where it leaves on a tangential path. **ii) Dual Peening** – Dual peening further enhances the fatigue performance from a single shot peen operation by re-peening the same surface a second time with smaller shot and lower intensity. Large shot leaves small peaks and valleys in the material surface even after 100% coverage has been achieved. Peening the surface a second time drives the peaks into the valleys, further increasing the compressive stress at the surfaces.

iii) Strain Peening – Where dual peening increases the compressive stress on the outer surface of the compressive layer, strain peening develops a greater amount of compressive stress throughout the entire compressive layer. This additional stress is generated by preloading the part within its elastic limit prior to shot peening. When the peening media impacts the surface, the surface layer is yielded further in tension because of the preloading. The additional yielding results in additional compressive stress when the metal's surface attempts to restore itself.

iv) Laser-shot Peening – Laser-shot peening utilizes shock waves to induce residual compressive stress. The primary benefit of the process is a very deep compressive layer with minimal cold working. Layer depths up to 0.40" on carburized steel and 0.100" on aluminium alloys have been achieved. Mechanical peening methods can only produce 35% of these depths.

v) Centrifugal blast wheel: The Centrifugal blast wheel consists of a high speed paddle wheel. Shot media is introduced in the centre of the spinning wheel and propelled by the centrifugal force by the spinning paddles towards the part by adjusting the media entrance location, effectively timing the release of the media.

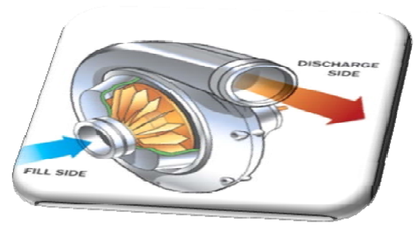

Fig: 3.2.2: Centrifugal blast wheel

3.2.3 Impact on Fatigue life of piston due to Shot peening:-

Piston is one of the important components in internal combustion engines. They are employed in different type of engines from single cylinder engine to large multi cylinder diesel or petrol engine. The piston is one of the most critically loaded components as it experiences cyclic loads in the form of thermal and pressure load during its service life. Fatigue is a source of piston damages. Fatigue is a major consideration in the design and performance evaluation of materials, components and structures since most of the all mechanical failures are attributed to fatigue fractures, especially in engine parts. The investigation emphasized that this cost could be significantly reduced by using proper and efficient design, manufacturing & various processes. Such studies are necessary to enhance the competitiveness of the vehicle components and their application in the automotive industry. Efficient design manufacturaring methods help in enhance performance and efficient operation of piston & finally operation of engine. Shot peening is one of the process to enhance fatigue life of piston components.

3.2.5 Residual stress field due to shot peening:-

Compressive residual stresses are widely used to enhance fatigue life, e.g. in shot peening. Shot peening parameters are still chosen empirically via Almen strip deflection, and little reliable information is available in the literature concerning values of residual stress as a function of alloy and shot peening conditions (coverage, peening intensity, angle, type of shot).

Residual stresses can be defined as self-equilibrating internal stresses existing in a free body which has no external forces or constraints acting on its boundary. These stresses arise from the elastic response of the material to plastic deformation. Therefore, shot peening which causes plastic deformation in the surface layers of the material, causes residual stresses in these layers because of the constraining effect of the bulk material (internal layers) where plastic deformation is minimal. In return, the surface layers also constrain the bulk material. Therefore, the bulk material gains some residual stresses even though it may not have any plastic deformations.

4 Method for shot peening:-

In the case of fatigue analysis Air blast system or conventional method is utilized. In this method media is introduced by various methods into the path of high pressure air and accelerated through a nozzle directed at the part to be peened.

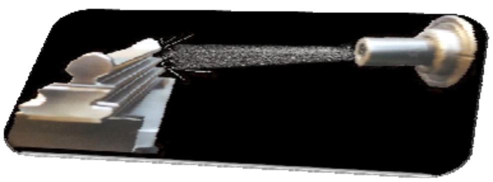

Fig: 4.2 Air blast system

4.3 Shot peening materials:-

In this case two types of materials are selected

i) Target materials:-

The material will be selected for target is aluminum. The applications of Aluminum (Al) use have extended into the area of the lightening of engine parts. Shot peening is widely used as a processing tool to increase the fatigue and wear resistance of engine of carbon or alloy steels, etc. the influences of shot peening on the fatigue life improvement of aluminum alloys vibrating cylinder block of a new two-stroke free piston engine. It is concluded that forged surface finish conditions found the highest life after the shot pening process. shot peening process is the promising surface treatments for aluminum alloy parts to increase the fatigue life of the free piston linear engine cylinder block

ii) Shot materials:-

The material will be selected for shot is steel. Most peening however, is carried out with cast steel shot that has been "tempered" after casting in order to improve its toughness. This is because it is the most cost-effective material and is suitable for peening most steel components.

6 Controlling the Shot peening Process:-

6.1 Media:-

Media control involves using high quality shot that is mostly round and of uniform size and shape. The diameter of the shot should be the same through out the media. If the shot diameter is not uniform, each individual shot will have a significantly different mass. This exposes the material surface to varying impact energies that create non uniformities. These non uniform layers will create inconsistent fatigue results.

6.2 Intensity:-

Intensity control involves changing the media size and shot velocity to control the energy of the shot stream. Using larger media or increasing the velocity of the shot stream will increase the intensity of the shot peening process. To determine what intensity has been achieved, Almen strips are mounted to Almen blocks and the shot peening process is performed on a scrap part. An Almen strip is a strip of SAE 1070 spring steel that, when peened on one side, it will deform into an arc towards the peened side due to the induced compressive stresses from the shot peening process. By measuring the height of the arc, the intensity can be reliably calculated. This process is done before the actual peening process on production parts to verify the peening process is correct. The Almen strips also control how long the material is exposed to the shot peening process. The time to expose a material is determined from the saturation point on a saturation curve. The saturation curve is a plot of Almen strip arc height vs Time. The saturation point is defined as the point on the curve where doubling the exposure time produces no more than a 10% increase in arc height.

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