FATIGUE STRENGTH TO THE DIFFERENT TYPE OF SPECIMENC AND SHAPE

`UMAYR HASAN BIN SOHAIMI

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Faculty of Mechanical Engineering
Universiti Malaysia Pahang

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ABSTRACT

The fatigue properties of metals are quite structure-sensitive. This project will study the endurance of some materials such as Aluminum, Mild Steel, Brass and Copper using fatigue testing method. Raw materials are first being cut using Horizontal Bandsaw machine. Then, they are form to the desired geometry using CNC Lathe machine. After specimens are prepared, experiment is performed using Fatigue Tester. The purpose of this study wants to know the fatigue limit that a materials can endured. Result shows that mild steel has the highest load cycles that it can endured and follows with brass, aluminum and copper. The specimens' distance to the load also influenced the endurance limit of a specimen.

ABSTRAK

Sifat-sifat kelelahan sesuatu logam adalah suatu struktur yang agak sensitif. Projek ini ialah untuk mangkaji ketahanan beberapa bahan seperti aluminium, besi ringan, kuprum dan tembaga menggunakan cara ujian lesu. Pertamanya, bahan mentah dipotong menggunakan mesin "Horizontal Bandsaw". Kemudian, ia dibentuk kepada geometri yang dikehendaki menggunakan mesin "CNC Lathe". Selepas bahan uji kaji disediakan, eksperimen dijalankan menggunakan mesin ujian kelesuan. Tujuan kajian adalah untuk mengetahui tahap ketahanan sesuatu bahan. Keputusan menunjukkan besi ringan mencatatkan pusingan bebanan terbanyak diikuti tembaga, aluminium dan kuprum. Jarak bahan uji kaji daripada beban juga mempengaruhi ketahanan sesuatu bahan uji kaji.

TABLE OF CONTENTS

3 METHODOLOGY

4 RESULT AND DISCUSSION

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Project Background

Fatigue is a localized damage process of a component produced by cyclic loading. It is the result of the cumulative process consisting of crack initiation, propagation, and final fracture of a component. During cyclic loading, localized plastic deformation may occur at the highest stress site. This plastic deformation induces permanent damage to the component and a crack develops. As the component experiences in increasing number of loading cycles, the length of the crack increases. After a certain number of cycles, the crack will cause the component to fail. The part fails at a stress level below that at which failure would occur under static loading. This phenomenon is known as fatigue failure, and it is responsible for the majority of failures in mechanical components.

The fatigue testing method involve testing specimen under various states of stress amplitude, the number of cycles it takes to cause total failure of the specimen or part is recorded. Stress amplitude is defined as the maximum stress, in tension and compression, to which specimen is subjected.

A typical plot known as S-N curves are based on complete reversal of the stress that is, maximum tension, the maximum compression, the maximum tension and so on. Then maximum stress to which the material can be subjected without fatigue failure, regardless the number of cycles, is known as the endurance limit or fatigue limit.

The preparation of the specimens must be done carefully especially when cutting the materials. Poor condition of cutting process can cause an error on the data.

The data from the experiment will be analyzed and comparison will be made. Some recommendation will be included in the conclusion.

1.2 Problem Statement

Ductile cast iron is a cast iron with spheroidal graphite. Because of high strength, high toughness, good machinability, and low cost, ductile cast irons are used widely in the critical automotive parts as crankshafts, front wheel spindle supports and truck axles. The mechanical properties of ductile cast irons are directly related to their matrix microstructure. As-cast matrix microstructure of ductile cast irons may be entirely ferritic, entirely pearlitic, or a combination of ferrite and pearlite, with spheroidal graphite distributed in the matrix. These micro structural features are affected by the solidification–cooling rate associated with the section size of the castings as well as that of the alloying elements. Bainite and martensite are not found in as-cast structures because they are formed by heat treatment. The matrix structure can be altered in subsequent heat treatment processing. However, the amount and form of the graphite in ductile cast iron are determined during solidification and cannot be altered by subsequent heat treatment. All of the mechanical properties of this class of materials are a result of the graphite being substantially or wholly in the spheroidal nodular shape.

The fatigue performance of cast irons, in general, is influenced by graphite morphology, matrix microstructure and tensile strength, specimen size, surface condition, surface degradation such as corrosion, and the type of loading stress (e.g., axial, bending, reversed bending, torsion). The free graphite in cast iron acts as an inherent notch that increases stress concentrations for fatigue crack initiation. Therefore, the fatigue performance of cast irons is influenced greatly by the quantity, size, and shape of the graphite phase as well as its interaction with the matrix. Thermal–mechanical surface hardening processes are commonly used to improve the wear and fatigue resistance of ductile iron castings.

In operation, crankshafts are generally subjected to torsion stress and bending stress due to self-weight or weights of components or possible misalignment between journal bearings. Thus, these rotating components are susceptible to fatigue by the nature of their operation and the fatigue failures are generally of the torsion and rotating-bending type. Fatigue failures start at the most vulnerable point in a dynamically stressed area particularly where there is a stress raiser. The stress raiser may be mechanical or metallurgical in nature, or sometimes a combination of the two. Mechanical stress raisers are non-uniformities in the shape of the crankshafts such as step changes in diameter, sharp corners and surface discontinuities like notches and machining marks etc. Metallurgical stress raisers may be quench cracks, corrosion pits, gross metallic inclusions, brittle second-phase particles, etc. Also, the microstructure of the crankshaft material plays a vital role not only in the initiation of fatigue failures but also during the progressive growth of the fatigue crack to cause failure of the component.

In the present study, a failed crankshaft used in a truck with a 6 cylinder 115 HP diesel engine has been examined for the cause of failure. The premature breakage of a diesel engine crankshaft was reported from an automotive repair shop. The general appearance and close-up view of the fracture location of the failed crankshaft. Failure of the crankshaft occurred after about 400 h in service, resulting in catastrophic failure of the engine. Chief technician of the automotive repair shop reported that crankshafts were often failed with similar damage before completion of warranty period.

1.3 Project Objectives

a) To investigate the fatigue limit to the different type of specimen and shapes under fixed loading using fatigue testing method.
b) To analyze the endurance limit of selected materials and make a comparison from the data.

1.4 Project Scopes

a) To study about fatigue limit using fatigue tester on selected materials under fixed loading.
b) To choose different specimens with different shapes.
c) To fabricate the specimens and conduct a fatigue experiment on different type of specimens and shapes.
d) To gathering the data from the experimental and analyze the failure mode for different specimens.
e) To analyze and compare the results.

CHAPTER 2

LITERATURE REVIEW

2.1 Fatigue

In narrow sense, the term fatigue of materials and structural components means damage and damage due to cyclic, repeatedly applied stresses. In a wide sense, it includes a large number of phenomena of delayed damage and fracture under loads and environmental conditions.

It is expedient to distinguish between high-cycle (classic) and low-cycle fatigue. If plastic deformations are small and localized in the vicinity of the crack tip while the main part of the body is deformed elastically, then one has high-cycle fatigue. If the cyclic loading is accompanied by elasto-plastic deformation in the bulk of the body, then one has a low-cycle fatigue. Usually we say low-cycle fatigue if the cycle number up to the initiation of a visible crack or until final fracture is below 10^4 Or 5.10^4 cycles. [Vladimir V.Bolotin, 1999]

In materials science, fatigue is the progressive, localized, and permanent structural damage that occurs when a material is subjected to cyclic or fluctuating strains at nominal stresses that have maximum values less than (often much less than) the static yield strength of the material. The resulting stress may be below the ultimate tensile stress, or even the yield stress of the material, yet still cause catastrophic failure.

A practical example of low-cycle fatigue would be the bending of a paperclip. A metal paperclip can be bent past its yield point (i.e., bent so it will stay bent) without breaking, but repeated bending in the same section of wire will cause the material to fail.

2.1.1 Fatigue Strength

Fatigue strength is defined as the maximum stress that can be endured for a specified number of cycles without failure. Low cycle fatigue strength approaches the static strength. When the cycle number exceeds to one limit, the fatigue strength falls to fraction of the static strength.

The fatigue strength is the value of the alternating stress that results in failure by fracture after a specific number of cycles of load application. It can also be the ordinate of the σ-N (stress vs. number of cycles to failure) curve.

The fatigue behavior of a specific material, heat-treated to a specific strength level, is determined by a series of laboratory tests on a large number of apparently identical samples of that specific material.

The specimens are machined with shape characteristics which maximize the fatigue life of a metal, and are highly polished to provide the surface characteristics which enable the best fatigue life.

A single test consists of applying a known, constant bending stress to a round sample of the material, and rotating the sample around the bending stress axis until it fails. As the sample rotates, the stress applied to any fiber on the outside surface of the sample varies from maximum-tensile to zero to maximum-compressive and back. The test mechanism counts the number of rotations (cycles) until the specimen fails. A large number of tests is run at each stress level of interest, and the results are statistically massaged to determine the expected number of cycles to failure at that stress level.

The cyclic stress level of the first set of tests is some large percentage of the Ultimate Tensile Stress (UTS), which produces failure in a relatively small number of cycles. Subsequent tests are run at lower cyclic stress values until a level is found at which the samples will survive 10 million cycles without failure. The cyclic stress level that the material can sustain for 10 million cycles is called the Endurance Limit (EL).

2.1.2 Fatigue Strength Testing

A failure that results from such cyclic loads is called a fatigue failure. Since many structural components are subjected to cyclic loads it is necessary for the design engineer to have some quantitative measure of the material's ability to withstand such repeated loads. Quantitative data for the fatigue properties of a given material are obtained by subjecting a number of standard specimens to cyclic loads until fracture occurs. [Joseph Datsko, 1997]

The objective of the fatigue strength or fatigue limit test is to estimate a statistical distribution of the fatigue strength at a specific high-cycle fatigue life. Among many fatigue strength tests methods, the staircase method (often referred as the up-and-down method) is the most popular one that has been adopted by many standards to asses statistical of a fatigue limit.

In this test, the mean fatigue limit has to first estimated, and a fatigue life test is then conducted at a stress level a little higher than the estimated mean. If the specimen fails prior to the life of interest, the next specimen has to be tested at a lower stress level. Therefore, each test is dependent on the previous test results, and the test continuous with a stress level increased or decreased.

2.2 Fatigue Damage Processes

Fatigue is gradual process of damage accumulation that proceeds on various levels beginning from the scale of the crystal lattice, dislocations and other objects of solid state physics up to the scales of the structural components. Three or four stages of fatigue damage are usually distinguishable. In the first stage, the damage accumulation occurs on the level of grains and intergranular layers. The damage is dispersed over the volume of a specimen or structural component, or at least, over the most stressed parts. At the end of this stage, nuclei of microscopic cracks originate, i.e., such aggregates of micro cracks that are strong stress concentrators and under the following loading, have a tendency to grow. Surface nuclei usually can be observed visually (at least with proper magnification). The second stage is the growth of cracks whose depth is small compared with the size of the cross section. At the same time, the sizes of these cracks are equal to few characteristic scales of microstructure, say, to several grain sizes. Such cracks are called small cracks. The number of small cracks in a body may be large. The pattern of their propagation is different from that of completely developed microscopic cracks. Small cracks find their way through the nonhomogeneous material. Most of them stop growing upon meeting some obstacles, but one or several cracks transform into microscopic, “long” fatigue cracks that propagate in a direct way as strong stress concentrators. This process forms the third stage of fatigue damage. The fourth stage is rapid final fracture due to the sharp stress concentration at the crack front and/or the expenditure of the material’s resistance to fracture.

The initiation and following growth of a microscopic crack are schematically shown in Figure 1 for the case of a polycrystalline material under uniaxial cyclic tension. Nuclei appear near the surface of the specimen, in particular, in the local stress concentration domains as well as near the damaged or weakest grains. The initial slip planes and micro cracks in grains are oriented mostly along the planes with maximal shear stresses. Small cracks are inclined, at least approximately, in the same directions. These cracks grow through the grains, intergranular boundaries or in a mixed way. When one of the small cracks become sufficiently long, the direction of its growth changes: the crack propagates into the cross section of the specimen, in the so-called opening mode. Such a “long” microscopic crack intersects in its growth a large number of grains. Therefore, this growth is determined mainly with averaged properties. The border between small and “long” cracks is rather conditional. In particular, it depends on the ratio of the current crack size *a* and the characteristic size of grains. If the grain size is of the order of 0.1 m, a crack may be considered as “long” when it reaches the magnitude *a* =0.5 mm or 1 mm. [Vladimir V. Bolotin, 1999]

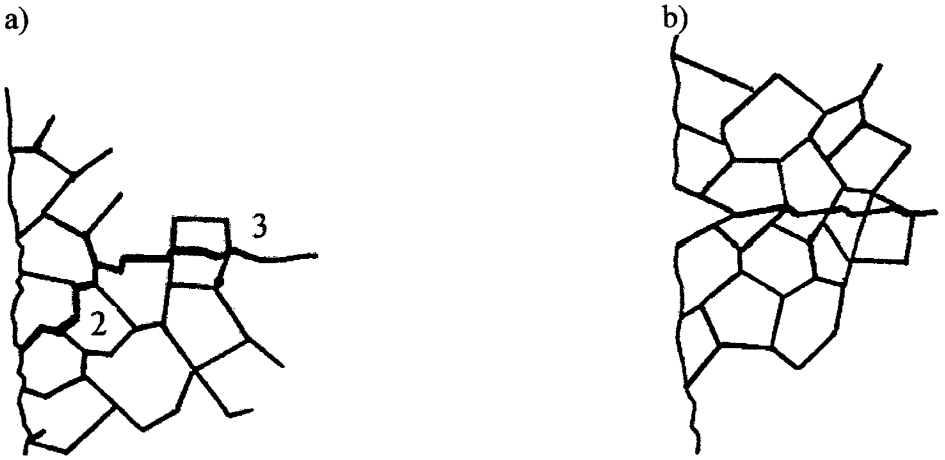

Figure 2.1: Fatigue crack initiation in polycrystalline material: (a) near the regular surface; (b) near a strong stress concentrator

The ratio of duration of these stages varies to a large extent depending on material properties, type of loading and environmental conditions. The first two stages are absent if a crack propagates from an initial microscopic crack, sharp crack-like defector another strong stress concentrator (Figure 2.1). In this case the position of the microscopic crack is condition beforehand, and the crack begins to propagate after a comparatively small number of cycles. On the other hand, for very brittle materials the final fracture may occur suddenly, without the formation of any stable microscopic cracks. For example, it may be a result that micro crack density attains a certain critical level.

2.3 Fatigue Failure

Failure is one of most important aspects of material behavior because it is directly influent the selection of material for certain application, the method of manufacturing and service life of component.

The majority of engineering failures are caused by fatigue. Fatigue failure is defined as the tendency of a material to fracture by means of progressive brittle cracking under repeated alternating or cyclic stresses of intensity considerably below the normal strength. Although the fracture is of a brittle type, it may take some time to propagate, depending on both the intensity and frequency of the stress cycles. Nevertheless, there is very little, if any, warning before failure if the crack is not noticed. The number of cycles required to cause fatigue failure at a particular peak stress is generally quite large, but it decreases as the stress is increased. For some mild steels, cyclical stresses can be continued indefinitely provided the peak stress (sometimes called fatigue strength) is below the endurance limit value.

A good example of fatigue failure is breaking a thin steel rod or wire with your hands after bending it back and forth several times in the same place. Another example is an unbalanced pump impeller resulting in vibrations that can cause fatigue failure.

The type of fatigue of most concern in circuit cards, gasoline, diesel, gas turbine engines and many industrial applications is thermal fatigue. Thermal fatigue can arise from thermal stresses produced by cyclic changes in temperature.

Fundamental requirements during design and manufacturing for avoiding fatigue failure are different for different cases and should be considered during the design phase.

Fatigue failures almost always begin at the surface of a material. The reasons are that

(a) The most highly-stresses fibers are located at the surface (bending fatigue) and
(b) The intergranular flaws which precipitate tension failure are more frequently found at the surface.

Suppose that a particular specimen is being fatigue tested. Now suppose the fatigue test is halted after 20 to 25% of the expected life of the specimen and a small thickness of material is machined off the outer surface of the specimen, and the surface condition is restored to its original state. Now the fatigue test is resumed at the same stress level as before. The life of the part will be considerably longer than expected. If that process is repeated several times, the life of the part may be extended by several hundred percent, limited only by the available cross section of the specimen. That proves fatigue failures originate at the surface of a component.

Fatigue failure is also due to crack formation and propagation. A fatigue crack will typically initiate at a discontinuity in the material where the cyclic stress is a maximum. Discontinuities can arise because of:

a) Design of rapid changes in cross-section, keyways, holes, etc. where stress concentrations occur.

b) Element that roll and/or slide each other (bearings, gears, cams) under high contact pressure, developing concentrated subsurface contact surfaces that can cause pitting from after many cycles of the load.

c) Carelessness in locations of stamp marks, tool marks, scratches, and burrs; poor joint design; improper assembly; and other fabrication faults.

d) Composition of the material itself as processed by rolling, forging, casting, extrusion, drawing and heat treatment. Microscopic and submicroscopic surface and subsurface discontinuities arise. [Joseph E Shigley, Charles R. Mischke, Richard G. Budynas, 2004]

Fatigue fracture typically occurs in material of basically brittle nature. External or internal cracks develop at pre-existing flaws or fault of defects in the material; these cracks then propagate and eventually they lead to total failure of part. The fracture surface in fatigue is generally characterized by the term “beach marks”.

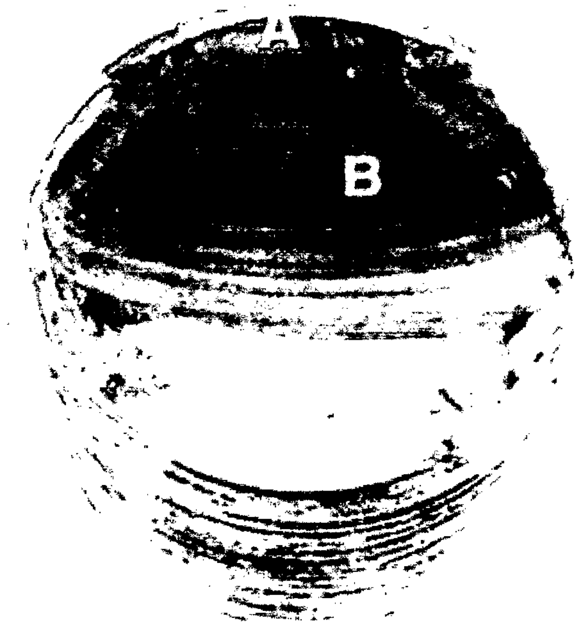

Figure 2.2: Fatigue failure of a bolt due to repeated unidirectional bending

The failure started at the thread root of A, propagated across most of the cross section shown by the "beach marks" at B, before final fast fracture at C.

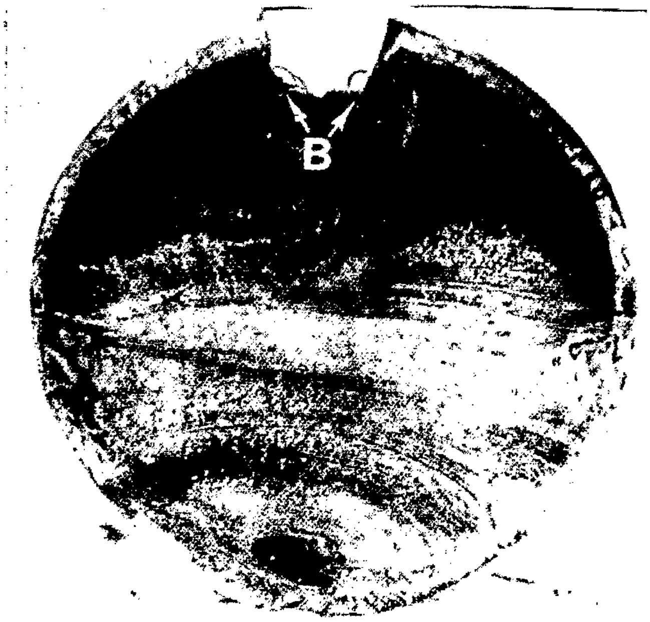

Figure 2.3: Fatigue fracture of an AISI 4320 drive shaft

The fatigue failure initiated at the end of the keyway at points B (discontinuity) and progressed to the final rupture zone is small, indicating that loads were low.

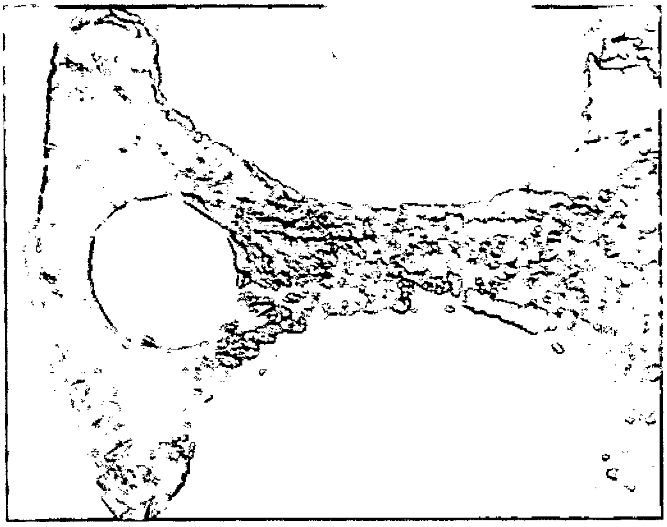

Figure 2.4: Fatigue fracture surface of a forged connecting rod of AISI 8640 steel

The fatigue crack origin is at the left edge, at the flash line of the forging, but no unusual roughness of the flash trim was indicated. The fatigue crack progressed halfway around the oil hole at the left, indicated by the beach marks, before final fast fracture occurred. Note the pronounced shear lip in the final fracture at the right edge.

The mode damage and final fracture depends on environmental conditions. At elevated temperature plasticity of most material increases, metal display creep, and polymers thermo-plastics behavior. At low temperatures plasticity of metal decreases, and brittle fracture becomes more probable. If structural component is subjected to both cyclic loading and variable thermal actions, mixed phenomena take place, such as creep fatigue; creep accelerated by vibration, and thermo-fatigue. The combination of fatigue and corrosion is called corrosion fatigue. It is type of damage typical for metals interacting with active media, humid air, etc. Hydrogen and irradiation embrittlement, as well as various wear and ageing processes, interact with fatigue, too. The delayed fracture occurs not only under constant or slowly varying loading. Typical examples are the delayed fractures of polymers and crack initiation and propagation in metals under the combination of active environment and non-cyclic loads. The latter kind of damage, opposite of corrosion fatigue, is called stress corrosion cracking. All these phenomena taken together form a class of damage frequently called static fatigue. Consider cyclic fatigue, calling it just fatigue. [Joseph Datsko, 1997]

The rate and direction of fatigue crack propagation is primarily controlled by localized stress and by the structure of the material at the crack. However, as with crack formation, other factors, such as environment, temperature, and frequency. Cracks will grow along planes normal to the maximum tensile stresses.

2.3.1 Endurance Limit

The fatigue limit or endurance limit is the largest value of alternating stress that will not result in fracture, regardless of the number of cycles of applied load. It is the value of alternating stress corresponding to the horizontal portion of the σ-N curve. In this case, the endurance limit is defined as the alternating stress that causes failures after some specified number of cycles. [Joseph Datsko, 1997]

It is important to remember that the Endurance Limit of a material is not an absolute nor fully repeatable number. In fact, several apparently identical samples, cut from adjacent sections in one bar of steel, will produce different EL values (as well as different UTS and YS) when tested, as illustrated by the S-N diagram below. Each of those three properties (UTS, YS, and EL) is determined statistically, calculated from the (varying) results of a large number of apparently identical tests done on a population of apparently identical samples.

2.3.2 Factors Influencing Fatigue Life

The resistance against fatigue depends essentially on a number of factors. Among them are: stress concentration, surface roughness, frequency of loading, loading history, residual stress-strain fields, temperature, environmental conditions, etc. Manufacturing process features such as heat treatment and cold deformation also affect fatigue life. [Dr. Yung-Li Lee, Jwo Pan, Richard Hathaway, Mark Barkey, 2005]

Magnitude of stress including stress concentrations caused by part geometry. Quality of the surface; surface roughness, scratches, etc. cause stress concentrations or provide crack nucleation sites which can lower fatigue life depending on how the stress is applied. For example, shot peening puts the surface in a state of compressive stress which inhibits surface crack formation thus improving fatigue life. Other surface treatments, such as laser peening, can also introduce surface compressive stress and could increase the fatigue life of the component. This improvement is normally observed only for high-cycle fatigue. Little improvement is obtained in the low-cycle fatigue régime.

The most recent development in the field of surface treatments utilizes ultrasonic energy to create residual compressive stresses that surpass those achieved by shot peening, laser peening, and other legacy methods. Ultrasonic Impact Technology operates within the harmonic frequency range of metals, allowing energy to be delivered deep into the material. Low amplitudes ensure that the metal is not overworked.

Material Type: Certain materials, such as steel, will never fail due to fatigue if the stresses remain below a certain level. Other materials, such as aluminum, will eventually fail due to fatigue regardless of the stresses the material sees. Surface defect geometry and location: The size, shape, and location of surface defects such as scratches, gouges, and dents can have a significant impact on fatigue life. Significantly uneven cooling, leading to a heterogeneous distribution of material properties such as hardness and ductility and, in the case of alloys, structural composition.

Size, frequency, and location of internal defects: Casting defects such as gas porosity and shrinkage voids, for example, can significantly impact fatigue life. In metals where strain-rate sensitivity is observed (ferrous metals, copper, titanium, etc.) strain rate also affects fatigue life in low-cycle fatigue situations. For non-isotropic materials, the direction of the applied stress can affect fatigue life. For most metals, fine-grained parts exhibit a longer fatigue life than coarse-grained parts.

Environmental conditions and exposure time can cause erosion, corrosion, or gas-phase embrittlements, which all affect fatigue life. The operating temperature over which the part is exposed to affects fatigue life.

2.3.3 Improving Fatigue Strength

Fatigue life is greatly influenced by the method of preparation of the surfaces of the part or specimen.

The fatigue strength of manufactured products can be improved overall by the following methods:

a) Inducing compressive residual stresses on surface for example, by shot peening or by roller burnishing.

b) Surface (case) hardening by various means.

c) Producing a fine surface finish and thereby reducing the effects of notches and other surface imperfection.

d) Selecting appropriate materials and ensuring that they are free from significant amounts of inclusions voids and impurities.

e) Eliminate or reduce stress raisers by streamlining the part

f) Avoid sharp surface tears resulting from punching, stamping, shearing, or other processes