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AMIN MORADI
Master of Technology in Transportation Engineering, Iran, moradi_amin85@yahoo.com

P. SRAVANA
Head of Department in Transportation Engineering, India, P.SRAVANA@gmail.com

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FATIGUE AND FRACTURE IN PAVEMENT

[1]AMIN MORADI & [2]P.SRAVANA

[1]Master of Technology in Transportation Engineering, Iran
[2]Head of Department in Transportation Engineering, India
[1]E-mail: moradi_amin85@yahoo.com

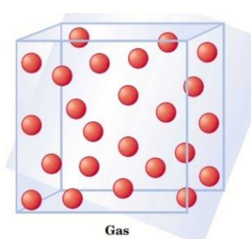
Abstract —This paper we present what is fatigue ?and what is fracture? we will discuse on design aspects related to fatigue failure, an important mode of failure in engineering components. Fatigue failure results mainly due to variable loading or more precisely due to cyclic variations in the applied loading . A fatigue failure begins with a small crack; the initial crack may be so minute and can not be detected. The crack usually develops at a point of localized stress concentration like discontinuity in the material, such as a change in cross section, a keyway or a hole.for design pavement flexible or regid pavement cycle life or how many percentage of material damaged.one parameter of design in all branch of engineering is standard of test of fatigue and fracture.for example in pavement number of axles ,number of tires ,thickness of pavement ,kind of Load is effect on fatigue and fracture**.**

Keywords*-Fatigue-fracture;thickness;load; pavement;material*

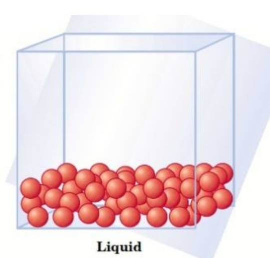
INTRODUCTION

what factors influence faigue and fracture, how to account them and finally how to design parts or components to resist failure by fatigue . Fatigue is a phenomenon associated with variable loading or more precisely to cyclic stressing or straining of a material. Just as we human beings get fatigue when a specific task is repeatedly performed, in a similar manner metallic components subjected to variable loading get fatigue, which leads to their premature failure under specific conditions.

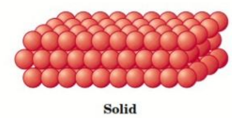
The three states of matter. A gas has no definite shape, and its volume is the volume of the container.A liquid has a definite volume but no definite shape. A solid has a definite shape and a definite volume.figure 1



Molecules far apart and disordered and Negligible interactions between molecules For liquid figure 2.



liquid intermediate situation. And solid figure 3.



Molecules close together and ordered Strong interactions between Molecules . At high temperatures, molecules possess a high kinetic energy and move so fast that the attractive forces between them are too weak to hold the molecules together. This situation is called the **gaseous state.** At lower temperatures, molecules move more slowly, to the point where the forces of attraction between them become important. When the temperature is low enough, a gas condenses to form a **liquid state.** Molecules in the liquid state still move past each other, but they travel much more slowly than they do in the gaseous state. When the temperature is even lower, molecules no longer have enough velocity to move past each other. In this **solid state,** each molecule has a certain number of nearest neighbors, and these neighbors do not change.

There are different types of fatigue/variable loading. The worst case of fatigue loading is the case known as fully-reversible load. One cycle of this type of loading occurs when a tensile stress of some value is applied to an unloaded part and then released, then a compressive stress of the same value is applied and released .

Often machine members subjected to such repeated or cyclic stressing are found to have failed even when the actual maximum stresses were below the ultimate strength of the material, and quite frequently at stress values even below the yield strength. The most distinguishing characteristics is that the failure had occurred only after the stresses have been repeated a very large number of times. Hence the failure is called fatigue failure .

FATIGUE FAILURE- MECHANISM:

Once a crack is initiated, the stress concentration effect become greater and the crack propagates. Consequently the stressed area decreases in size, the stress increase in magnitude and the crack propagates more rapidly. Until finally, the remaining area is unable to sustain the load and the component fails suddenly. Thus fatigue loading results in sudden,unwarned failure.

FATIGUE FAILURE STAGES :

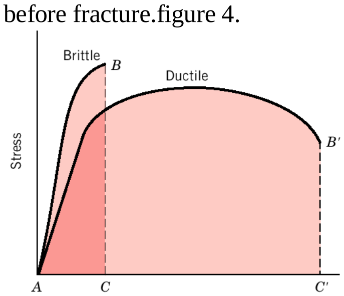
Thus three stages are involved in fatigue failure namely
-Crack initiation
-Crack propagation
-Fracture

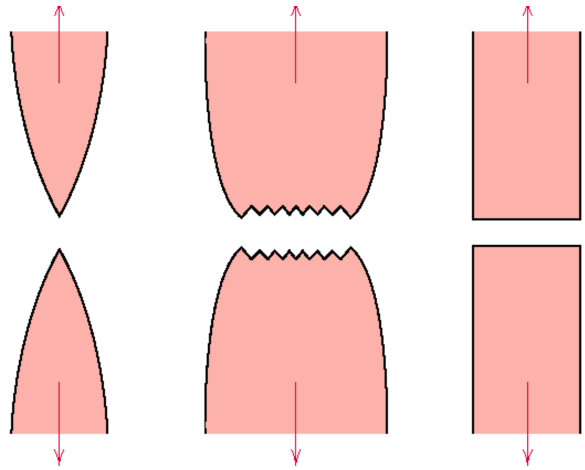
Areas of localized stress concentrations such as fillets, notches, key ways, bolt holes and even scratches or tool marks are potential zones for crack initiation.

• Crack also generally originate from a geometric discontinuity.

• This further increases the stress levels and the process continues, propagating the cracks across the grains or along the grain boundaries, slowly increasing the crack size.

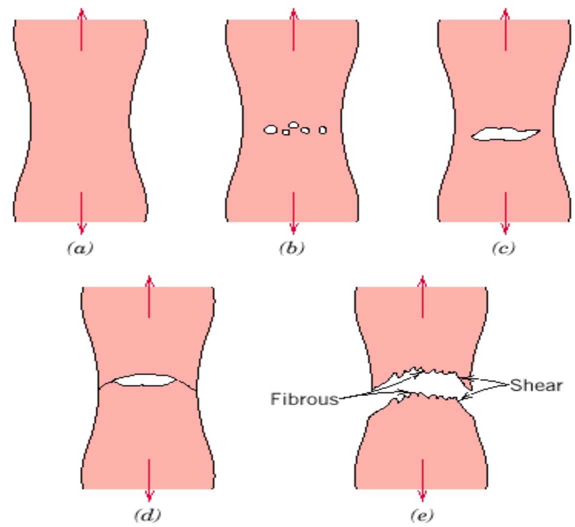
One of the most important concepts in Materials Science and Engineering is fracture. In its simplest form, fracture can be described as a single body separated into pieces by an imposed stress. For engineering materials there are two possible modes of fracture, ductile and brittle. In general, the main difference between brittle and ductile fracture can be attributed to the amount of plastic deformation (i.e., dislocation motion) that the material undergoes before fracture occurs. Ductile materials demonstrate large amounts of plastic deformation while brittle materials show little or no plastic deformation before fracture. that a tensile stress-strain curve represents the degree of plastic deformation exhibited by both brittle and ductile materials
before fracture.figure 4.





Highly ductile fracture (left),moderate ductility (center)
brittle fracture (right).figure 6.

The fracture process usually consists of several stages:figure 7.



The relationship between stress and cycles to failure are related using a S-N plot. The plot shows the applied max stress versus the amount of cycles it took for the material to fail, otherwise known as the fatigue life of a material.figure 8.

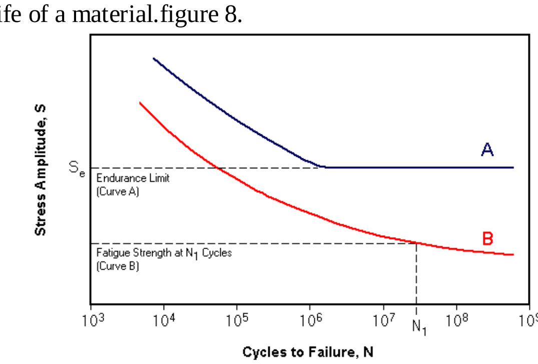


Figure 8

S-N plot showing a material that has an endurance limit (A) and one which does not have an endurance limit (B).
The above two curves exhibit two different kind of fatigue in materials. Curve A denotes a material that has a fatigue limit. A fatigue limit (also called an endurance limit) denotes the critical stress below which fatigue fracture will not happen. Curve B denotes a fatigue curve that does not have a fatigue limit. It does however have fatigue strengths. That is to say for a given stress their is a given fatigue life or number of cycles to failure of that material. The maximum number of cycles it takes for a material to fracture is called fatigue strength.
Fatigue fracture is a ductile fracture, and therefore occurs by non-uniform plastic deformation. Microcracks and voids form after a certain number of cycles and grow proportional to the number of cycles eventually grow large enough to overcome recovery mechanisms and move quickly to fracture.The rate of this crack nucleation is proportional to the frequency of the applied stress. Fatigue fracture is mostly

Centered on metals. Fatigue fracture is easily identifiable by outwardly arcing lines of deformation from the crack initiation point, which indicates gradual crack growth rather than sudden growth Also, the slow. crack growth creates fatigue striations whose displacement from one another is proportional to crack growth per cycle of stress.

HIGH-CYCLE FATIGUE :

High-cycle fatigue is when the number of cycles to failure is large, typically when the number of cycles to failure, N_f, is greater than 1000.

LOW-CYCLE FATIGUE :

Low- cycle fatigue is when the number of cycles to failure is small, typically when the number of cycles to
failure, Nf, is less than 1000.
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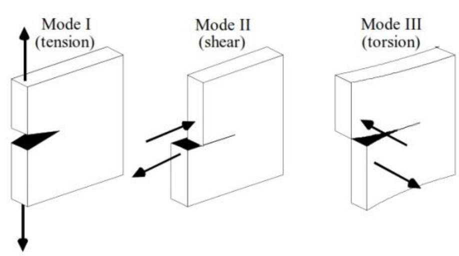
A fatigue crack can propagate in three modes, depending on the relative orientation of loading to the crack This study focuses on mode I crack growth - the most common crack
propagation mode.Figure 9.



Crack Propagation Stages:

Fatigue crack propagation can be divided into three stages as shown in Figure 10: crack initiation (CI), stable crack growth (SCG), and unstable crack growth (UCG).

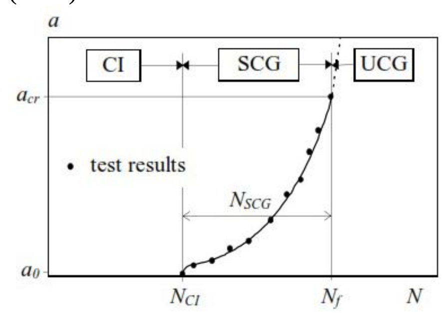


Figure 10 : Fatigue crack propagation stages.

CRACK INITIATION :

Crack initiation takes place at the crack initiators. The length of the initial crack is marked as and it is usually taken between 0.1 to 0.25 mm .The number of stress cycles corresponding to crack length a a0 in the a-N curve is referred to as the crack initiation life and it is noted N CI
(Figure 10).
The crack initiation life can be absolute and relative. The absolute crack initiation life depends on the magnitude of the local cyclic stress field around the stress concentrator. The relative crack initiation life (compared to the total fatigue life of the specimen) depends on the distribution of the local cyclic stress field around the stress concentrator.

STABLE CRACK GROWTH:

Stable crack growth takes place along a path perpendicular to the dominant principal stress.
The number of load cycles required to grow the crack from its initial length a0, to the critical length acr , is called the stable crack growth life and it is given the symbol NSCG. The total fatigue life,Nf, is the sum of the NCI and NSCG (Figure 10).

the influence of the stress distribution along the crack path on the relative crack initiation and stable crack growth lives. The plates in Figure 11. contain an elliptical hole at the center. In case a) , there is a relatively uniform stress distribution along the crack path which results in a long relative crack initiation life (Figure 2.8.a). However, in case

b), the non-uniform, rapidly decreasing stress distribution along the crack path results in a short relative crack initiation life (Figure 11.b).

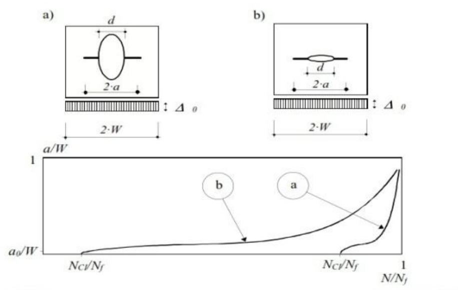


Figure 11 : Relative crack initiation life as a function of the stress distribution at the crack initiator : a) NCI >> NSCG ; b) NCI << NSCG.

UNSTABLE CRACK GROWTH :

If crack propagation has entered into the unstable growth stage, a ductile or brittle fracture of the detail can take place. This phase of the fatigue crack propagation is very short compared to the crack initiation and the stable crack growth phases. Since the unstable crack growth stage.

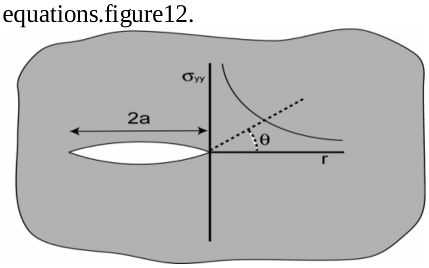
is only a small part of the total fatigue life, it is not important from a practical point of view.Therefore, modeling of the unstable crack growth stage will not be discussed further.

Load-Life Relationship (mathematics):

The load-life relationship used by the fracture mechanics

SHARP CRACKS

The above is very useful for finding the effect of features in the structure, but most cracks are long and have sharp tips. These can be of atomic dimensions in brittle materials. In 1939 Westergaard solved the stress field for an infinitely sharp crack in an infinite plate. The elastic stresses were given by the equations.figure12.



$$\sigma_{yy} = \frac{\sigma_o\sqrt{\pi a}}{\sqrt{2\pi r}}\cos\left\{\frac{\theta}{2}\right\}\left[1+\sin\left\{\frac{\theta}{2}\right\}\sin\left\{\frac{3\theta}{2}\right\}\right]$$

$$\sigma_{xx} = \frac{\sigma_o\sqrt{\pi a}}{\sqrt{2\pi r}}\cos\left\{\frac{\theta}{2}\right\}\left[1-\sin\left\{\frac{\theta}{2}\right\}\sin\left\{\frac{3\theta}{2}\right\}\right]$$

$$\tau_{xy} = \frac{\sigma_o\sqrt{\pi a}}{\sqrt{2\pi r}}\sin\left\{\frac{\theta}{2}\right\}\cos\left\{\frac{\theta}{2}\right\}\cos\left\{\frac{3\theta}{2}\right\}$$

All the equations separate into a geometrical factor and the stress intensity factor:

$$K = \sigma_0\sqrt{\pi a}$$

K determines the amplitude of the additional stress due to the crack over the whole specimen, but particularly at the crack tip where growth has to occur.

When θ = 0º the stress opening the crack has the value :

$$\sigma_{yy} = \frac{\sigma_o\sqrt{\pi a}}{\sqrt{2\pi r}} = \frac{K}{\sqrt{2\pi r}}$$

The value of K at which fracture occurs is the material-dependant .

Fracture Toughness:

$$K_{Ic} = \sigma_f\sqrt{\pi a}$$

For a fixed stress this defines the maximum stable crack length or for a fixed crack length the maximum stress.

there are a number of parameters K:

$$K_t = \frac{\sigma_{max}}{\sigma_o}$$

$$K = \sigma\sqrt{\pi a}$$

$$K_{Ic} = \sigma_f\sqrt{\pi a}$$

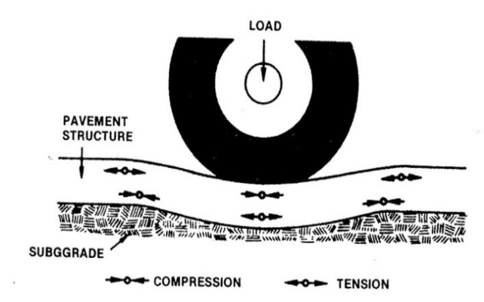
Kt= stress concentration factor (dimensionless)

K=stress intensity factor,KIc=critical stress factor.

What is pavement fatigue?

Fatigue is progressjve damage from many applications of a load. Pavement usually breaks up from fatigue failure.

Roads also bend under vehicle loads. As the pavement bends, its various layers are affected differently (see figure13). Like the metal rod/ the upper portion is compressed while the lower portion stretches. As bending causes fatigue, the pavement surfacing cracks allowing moisture into the pavement base and subgrade. This results in greater bending, further cracking and finally failure.



Effects of wheel loads

There are several basic vehicle wheel arrangements: single wheel, dual wheel, single axle/ and tandem axle. The maximum legal single axle load in Wisconsin is 20/000 Ibs. and the maximum tandem load is 34,000 Ibs. Loads per wheel equal the axle load divided by the number of wheels.

Pavement fatigue is measured by the number and weight of axle loads needed to make the pavement unusable.

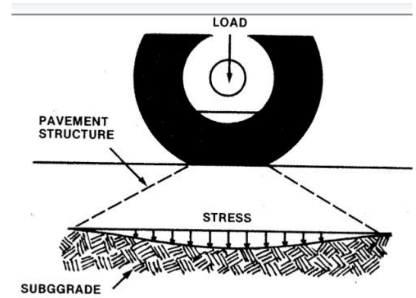
As each axle load is increased, the road can withstand fewer trips before it breaks up. If axle loads are decreased, the pavement will carry more vehicles before failing. The lower the wheel load, the less a pavement bends and consequently, the longer it lasts. Trucks are the primary concern because of their great weight.

Pavement damage increases rapidly with higher axle loads, and actually increases faster than the loads increase. One nine-ton axle load, for example, causes about ten times more damage than a five-ton axle load.

Information on the relative effects of axle loads and wheel arrangements on different pavements comes from the AASHTO road tests in Ottawa, III. These tests developed the damage unit, a simple method for measuring pavement damage based on the relationship between axle load and road damage. Eighteen thousand pounds (nine tons) yields one unit of damage in one pass. If a truck with a standard axle weight of 18,000 Ibs. makes 100 passes over a pavement, 100 units of pavement life are used up per axle. pavement damage increases faster than axle loads. A semi trailer with a five-ton front steering axle and two single nine-ton load axles carrying a 16,000 lb. pay load would use up 2.1 damage units. If a similar truck with two single ten-ton axles carries a 20,000 lb. payload, the payload increases by 25%, but pavement damage would increase by almost 50%. Furthermore, if the same truck were illegally overloaded to 24,000 Ibs. per axle, pavement damage would increase by 100% over the ten-ton load (and 300% over the nine-ton load), but the 28,000 lb. payload is only 40% larger.

Pavement thickness

Pavement thickness is a major factor in load capacity. Pavements are designed using the predicted number and weight of axle loads over the expected life. Pavement must be thick enough or strong enough to withstand stress for this period before it begins to break up from fatigue damage. The major component of fatigue is deflection or bending. Thicker pavements suffer less stress and deflection, and therefore, will last longer under heavy loads. Weakened roads are commonly strengthened by adding thickness through overlays or complete rebuilding.



NUMBER OF TIRES :

The number of tires (or wheels) is also important. Changing from dual tires to single tires, on a single axle load truck, will increase the pavement stress by 10-20% because the load is now concentrated in one spot rather than in two. The effect of dual wheels depends in part on pavement thickness. As depth increases, the stress caused by dual wheel loads becomes equivalent to single whee/loads.

NUMBER OF AXLES :

Tandem axles can carry much greater pay loads with little increase in pavement damage. A tandem load of 32,000 Ibs. will cause only 1.9 damage units .the pay load has been increased about 175% to 44,000 Ibs., while the resulting pavement damage has actually decreased by 10%. Tridem (three) axles are even better for reducing road damage. Tridem axles have 12 wheels on three axles arranged trailing one another under the truck. A truck with an 80,000 lb. gross load on a tridem would cause only two-thirds the damage of a tandem carrying the same load. In fact, it is possible to do less damage to the pavement with triderns and carry even even more payload. Since different truck configurations can carry greater loads without necessarily causing more road damage, it makes sense to post several load limits on roads which regularly carry different truck configuration.

CONCLUTION :

Pavement base

Since the majority of local roads are constructed with relatively th i n (2 II -4 ") asphaIt surfacing, the strength of the aggregate base becomes very important in the road's ability to support loads. A good base increases the overall strength of the road by distributing load effects to the soil beneath it and provides drainage to help protect against frost heave . Any weakening of the underlying soil by moisture or freeze-thaw action will greatly diminish the road's strength. Because underlying soils, field conditions, and pavement materials vary, a deflection (strength) test can be very helpful in evaluating a pavement for future maintenance and improvement.

•Pavement fatigue damage increases as pay load increases .

•Fatigue damage increases more rapidly with increased axle load than does the pay load.

•Pavement fatigue damage is reduced by using axle arrangements which spread the load out. Tandem is better than single, and tridem is better yet.

•Dual wheels also spread out the load.

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