Fracture, Fatigue and Failure of Materials
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Lecture 46
Fatigue Crack Propagation (Contd.)

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NPTEL ONLINE CERTIFICATION COURSES

Fracture, Fatigue and Failure of Materials

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Module 02: Fatigue

Lecture 46: Fatigue Crack Propagation

Hello everyone, we have come to the 46th lecture of the course Fracture, Fatigue and Failure of Materials.

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Concepts Covered

- Fatigue Crack Propagation in Regime I
- Influence of microstructure
- Design dilemma

And in this lecture, we will be talking about fatigue crack propagation and particularly, we will be talking about the propagation in regime 1 and most importantly the influence of microstructure in the crack growth rate or most precisely the threshold value of the stress intensity factor range for the growth of the crack and the influence of microstructure on that will be elaborated. And at the same time, we will be also looking into the design dilemma that the engineers face while designing a component which needs to be survived and has to have a higher fatigue performance.

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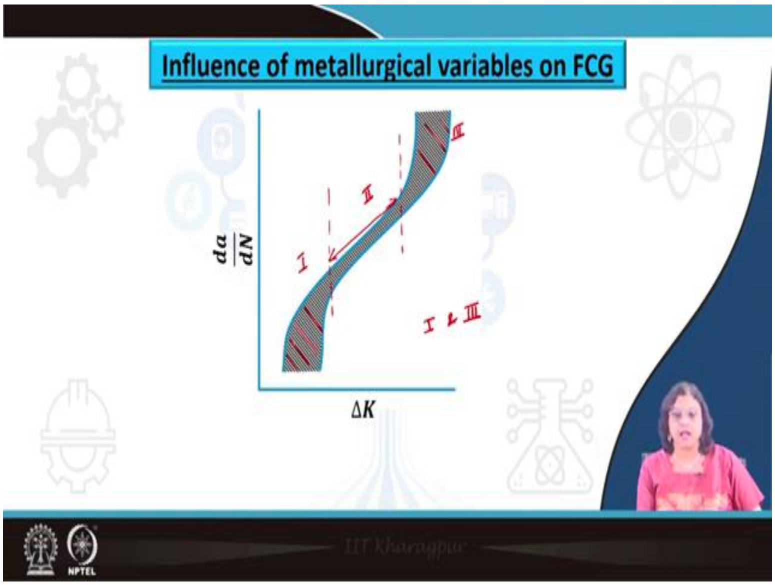

Influence of metallurgical variables on FCG

So, in the last lecture, we have seen that how ΔK_{th} or the threshold value for the onset of the crack growth can be controlled and there are other parameters such as the R-ratio, the mean value of the stress intensity factor or the environment that can be altered in turn to get a different value of the ΔK_{th} and particularly we aim to achieve higher and higher value of ΔK_{th} so, that the growth of the crack can be hindered up to certain extent or the overall onset for the crack growth can be delayed and that may lead to an enhancement in the overall fatigue life or for that matter fatigue performance of the material. So, we often aim to do that.

So, this slide here actually shows that da/dN versus ΔK curve, but most importantly, the shaded part here shows that this elaborated region are actually the ones which are mostly controlled by the metallurgical variable. So, if we are dividing this into 3 regimes as we have done earlier also. So, this is for regime I, regime II and regime III.

So, what we can see here that regime I and regime III are the ones which are particularly being controlled by the metallurgical variables such as the microstructure or other factors. On the other hand, regime II more or less have a steady state growth based on the Paris relation and we have also seen that how it actually covers major part of the life and how we can estimate the remaining life of a cracked or a notched component.

But again, of course, all the sections all the regimes are important in its own way and when we are talking about any particular regime, we always target to see that how we can have better and better performance that is the main purpose of understanding fatigue mechanism and to implement that in failure analysis that we want to have higher and higher performances.

So, when we are talking about regime I and we have seen that how the mean stress or the influence of environment can alter the behavior, we also need to see that how microstructure most importantly can control the fatigue threshold stress intensity factor range.

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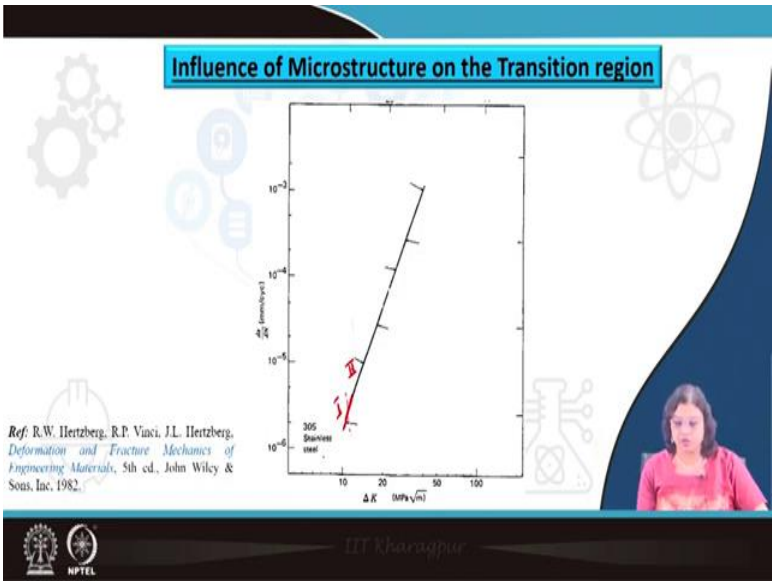
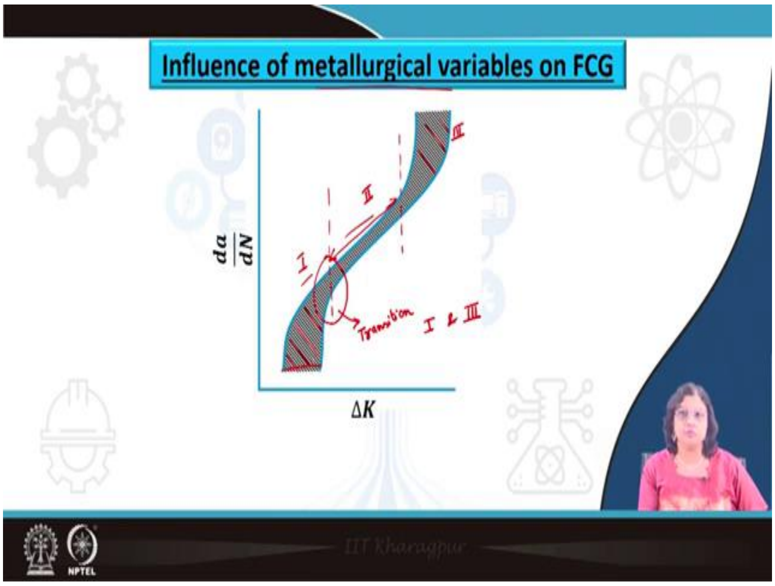
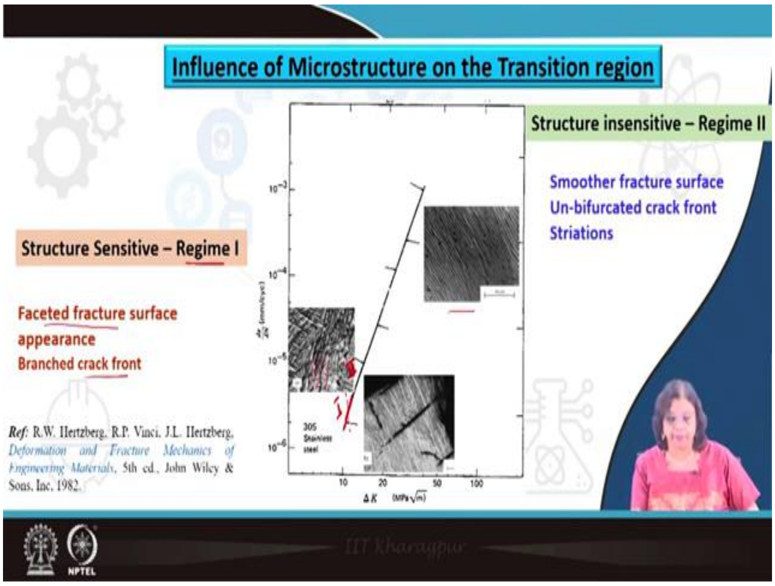


Influence of Microstructure on the Transition region

Ref: R.W. Hertzberg, R.P. Vinci, J.L. Hertzberg, *Deformation and Fracture Mechanics of Engineering Materials*, 5th ed., John Wiley & Sons, Inc, 1982.



Influence of metallurgical variables on FCG



Influence of Microstructure on the Transition region

Structure Sensitive – Regime I

Faceted fracture surface appearance

Branched crack front

Structure insensitive – Regime II

Smoother fracture surface

Un-bifurcated crack front

Striations

Ref: R.W. Hertzberg, R.P. Vinci, J.L. Hertzberg, *Deformation and Fracture Mechanics of Engineering Materials*, 5th ed., John Wiley & Sons, Inc. 1982.

To see that, to understand that actually, we need to look into this da/dN and versus ΔK curve more precisely and particularly, the transition between this regime I and regime II is what is significant. So, this one here shows just the onset of regime II and that means that the small part here is actually regime I. So, there is a different mechanism completely different mechanism is being followed for regime I and II and this transition is happening over this particular location.

So, let us focus more on this and this can be done based on the fracture surface analysis the fractography and all to understand that, how the transition is happening. Now, why we are talking about transition because, so, far we have seen that based on this previous curve that this I is having a completely different mechanism which is controlled by the metallurgical variables whereas II is not.

So, of course, something is happening at this particular transition regime and if we are able to focus on that, we should be able to find out that what are the exact reasons for which we can control the regime I in one way, but the regime II cannot be controlled in that way. And slowly from there, we will look into the importance of microstructure.

So, for now, let us focus on the da/dN versus ΔK curve and the fractographs associated with that. So, what happens for the case of regime I, which we have seen is a structure sensitive, structure means here microstructure.

Regime I is the one which is sensitive to the change in the microstructure, we will look into it in more details later on, but for now, let us see that what happens to the fractograph how we can understand this right from the fracture surface itself.

So, basically if we analyze the fracture surface after the failure, so, after it reaches regime III and we are looking onto the fracture surface of the broken specimen we can figure out up to what part was the regime I was active and that is based on the appearance of faceted fracture surface, not only that, there will be the branched crack front.

So, crack path was torturous as we have again seen in the last lecture how the crack path changes its direction very frequently and that can be also seen from the fractograph or from the microstructure taken right during the process of fatigue itself. Here you can see how the faceted surface can be seen from the fracture surface and these are the signatures that regime I has been active at that particular location.

On the other hand, if we are looking for the regime II, which is basically structure insensitive. So, microstructure does not control the behavior of the material or undergoing fatigue at regime II.

So, in such cases basically instead of a faceted fracture surface, we see a smoother fracture surface and there are not any bifurcated crack front that are seen here and most importantly what we can see into the structure or into the fractograph are the striations the presence of striations, which are the signature features particularly seen from region II, as you can see the striations clearly here. So, from the fracture surface itself, we can differentiate between the regime I and II, and where this transition is happening.

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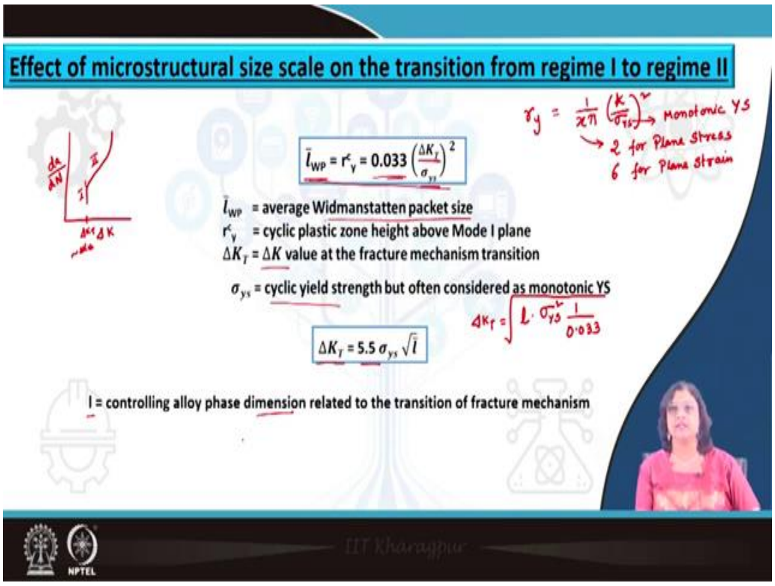

Effect of microstructural size scale on the transition from regime I to regime II

$$\boxed{\bar{l}_{WP} = r^c_y = 0.033\left(\frac{\Delta K_T}{\sigma_{ys}}\right)^2}$$

$\bar{l}_{WP}$ = average Widmanstatten packet size

r^c_y = cyclic plastic zone height above Mode I plane

ΔK_T = ΔK value at the fracture mechanism transition

σ_{ys} = cyclic yield strength but often considered as monotonic YS

$$\boxed{\Delta K_T = 5.5\,\sigma_{ys}\sqrt{l}}$$

l = controlling alloy phase dimension related to the transition of fracture mechanism

$r_y = \frac{1}{x\pi}\left(\frac{K}{\sigma_{YS}}\right)^2 \rightarrow$ Monotonic YS

$\rightarrow$ 2 for Plane Stress

6 for Plane strain

$\Delta K_T = \sqrt{l \cdot \sigma_{YS}^2 \frac{1}{0.033}}$

And if we are looking into the microstructure aspect it has been found particularly initially studied for steel and it has been found that a particular relation is being followed based on the microstructure size as well as the ΔK value for this transition.

Now, this kind of relation is noted basically that the l_{wp} which is the Widmanstatten packet size you know the microstructure is having this Widmanstatten packet. So, colonies which are having the dimension of l_{wp} and that is equivalent to $0.033(\frac{\Delta K_T}{\sigma_{ys}})^2$.

Now, this ΔK_T signifies the ΔK value at the fracture mechanism transition. So, if we are talking about the da/dN versus ΔK curve and if we are getting this as regime I and regime II and we are talking about this one here.

So, this is what is ΔK_T or where the transition is actually happening and this is more or less equivalent to ΔK_{th}, because we know that regime I has a very sharp slope and that means that ΔK_T is actually the one at which the crack growth rate is very very nominal or minimal and we can consider that as a ΔK_{th}.

So, that means that the packet size is directly proportional to the ΔK_T and inversely proportional to the yield strength of the material σ_{ys} is the cyclic yield strength. It is not just the yield strength we have seen earlier that when we are performing the cyclic loading, repeated loading, then there as the cyclic yield strength can be obtained as the 0.2 % offset based on the cyclic stress strain curve and this value could be different compared to the monotonic behavior we can we have seen that there could be cyclic hardening or softening.

So, right now since we are talking about the fatigue loading, we are considering the cyclic yield strength and the ΔK_T, which is the transition, at the point of transition the ΔK value.

Now, somehow this relation looks familiar to the plastic zone size, if you remember the plastic zone size, which is signified as r_y this could be under plane strain or plane stress is given by 1 by let us name this as $x\pi$, $(\frac{K}{\sigma_{ys}})^2$.

Now, that was in case of a monotonic loading, because we were talking about the fracture toughness testing under the application of tensile load, this x could be 2 for plane stress and this could be 6 for plane strain for the ideal plane stress or plane strain condition. And K is the stress intensity factor and this could be the critical value of the stress intensity factor at the point of fracture and σ_{ys} is is the monotonic yield strain of course, because we were so far talking about the monotonic loading itself.

So, this relation more or less is looks familiar to what we are seeing about the Widmanstatten packet size, which indicates that something has to be done with a plastic zone size somewhere, but before that, before going into that details, let us simplify this relation further with the fact that we were interested on the ΔK_T value.

How that ΔK_T is related to the microstructure size scale and a more simplified version would be just rearranging this relation as ΔK_T will be $l \times \sigma_{ys}$ and $\frac{1}{0.033}$ and this entire thing has to be under the root so, if we do that we will come up to a value like this as $5.5\sigma_{ys}\sqrt{l}$, the l here instead of the Widmanstatten packet size we consider l as the the dimension related to the transition of fracture mechanism.

So, this dimension could be anything any microstructure parameters or micro structural features that is of interest and this could be like the grain size, the colony size, lath size, whatever is of interest and whichever can act as a hindrance to the growth of the crack.

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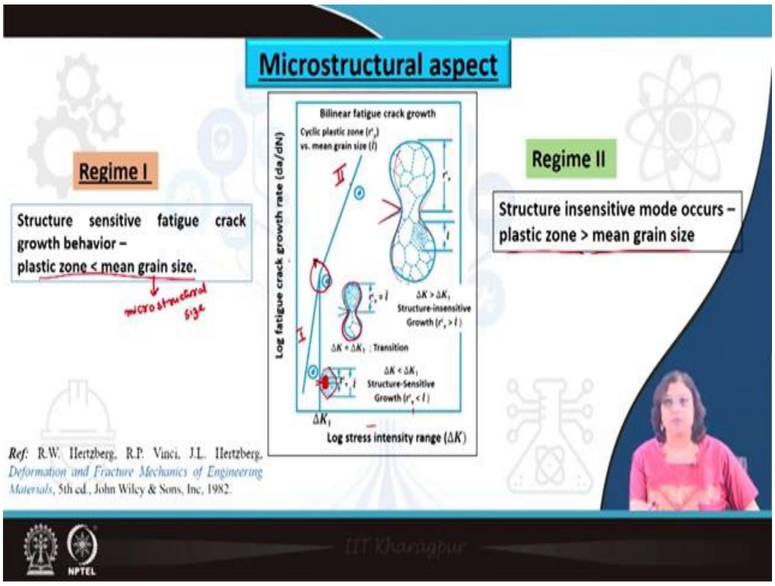

Microstructural aspect

Regime I

Structure sensitive fatigue crack growth behavior –
plastic zone < mean grain size.

microstructural size

Regime II

Structure insensitive mode occurs – plastic zone > mean grain size

Ref: R.W. Hertzberg, R.P. Vinci, J.L. Hertzberg, *Deformation and Fracture Mechanics of Engineering Materials*, 5th ed., John Wiley & Sons, Inc, 1982.

So, let us now once again go back to the concept when we found a relation between the plastic zone size as well as a Widmanstatten packet size versus the ΔK_T. So, what is being shown here once again is the da/dN versus ΔK curve.

But, apart from that what we are seeing here is for the case of regime I when there is a crack very small and because we are applying very small or low value of ΔK here, it forms a plastic zone size which is very very small.

So, this red part here and you can also see the grain size or any other microstructural size and the plastic zone size is completely encompassed within this grain size or microstructural size. So, for that matter the plastic zone size is not providing much of a hindrance to the growth of the crack, when we are talking about very high value of strain or stress intensity factor range at this point here, there we see that this is the crack and obviously, the plastic zone size now is quite big and this encompasses many, many grains within it to the plastic zone size is much bigger than the individual grain size.

So, of course, plastic zone size here has a very significant role fine, but at the point of transition, this plastic zone size, if it is of the same order as the microstructural features, then actually both of this act as to hinder the growth of the crack and that is what is happening at the transition.

So, at regime I, which is basically structure sensitive plastic zone size is much less than the grain size of the material, the average grain size or any other microstructural size for that matter. Let me write this down as microstructural size. On the other hand, for the case of regime II, which is structure insensitive here the plastic zone size is much greater than the microstructure and size that we have seen here for regime II. But at the point of transition, we can see that this plastic zone size is more or less equivalent to the microstructure size of the material.

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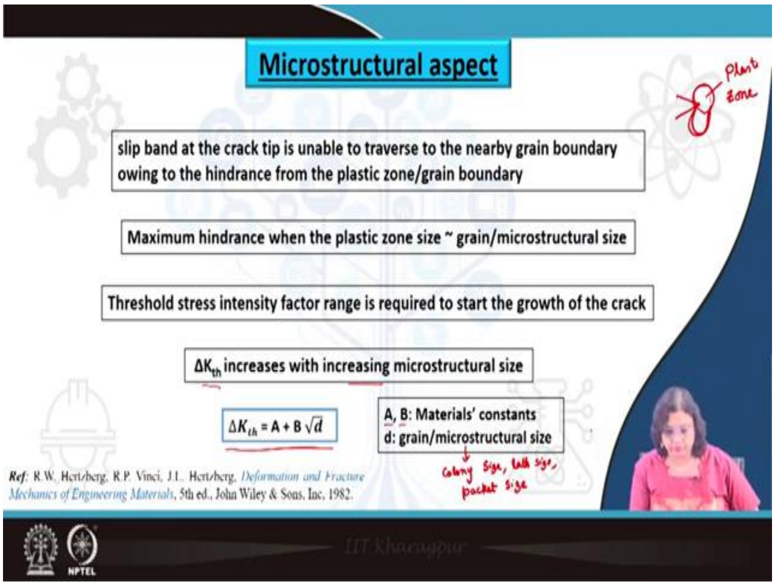

Microstructural aspect

slip band at the crack tip is unable to traverse to the nearby grain boundary owing to the hindrance from the plastic zone/grain boundary

Maximum hindrance when the plastic zone size ~ grain/microstructural size

Threshold stress intensity factor range is required to start the growth of the crack

ΔK_{th} increases with increasing microstructural size

$\Delta K_{th} = A + B\sqrt{d}$

A, B: Materials' constants
d: grain/microstructural size

Colony size, lath size, packet size

Plast zone

Ref: R.W. Hertzberg, R.P. Vinci, J.L. Hertzberg, *Deformation and Fracture Mechanics of Engineering Materials*, 5th ed., John Wiley & Sons, Inc, 1982.

And let us see what happens then basically, the slip band at the crack tip is hindering the growth of the crack and it is unable to traverse to the nearby grain boundary. And as a result, the growth of the crack is being delayed or stopped completely by this plastic zone size or the grain boundary both. Now, this maximum hindrance occurs when the plastic zone size is equivalent to the grain microstructural size.

So, that means that the crack has to overcome both this barrier, first of all the plastic zone size here and plastic zone as we have seen is not allowing the crack to grow. On the other hand, if there are grain boundaries, now grain boundaries also act to hinder the or stop the growth of the crack, so grain boundary at the defects with the crack has to overcome to move on to the neighboring grain.

So, that also simultaneously act as a defect now, when both of these are acting together certainly the growth of the crack will be stopped to its maximum extent and we need to apply a larger values of stress intensity factor to overcome both the barriers and for the crack to grow. So, that means that ΔK_{th} needs to be increased. So, that is why the ΔK_{th} increases with increasing microstructural size or it has a direct relation with the microstructural size.

So, let us quantify this strength that how the ΔK_{th} or the threshold value is related to the microstructural size. Actually, a particular relation like this is being followed where ΔK_{th} is equal to $A + B\sqrt{d}$. So, this A and B are the material constants that could vary from material to material and d is nothing but the microstructural size this could be once again grain size or colony size or lath size or packet size anything that is of importance and which the crack needs to overcome on its way.

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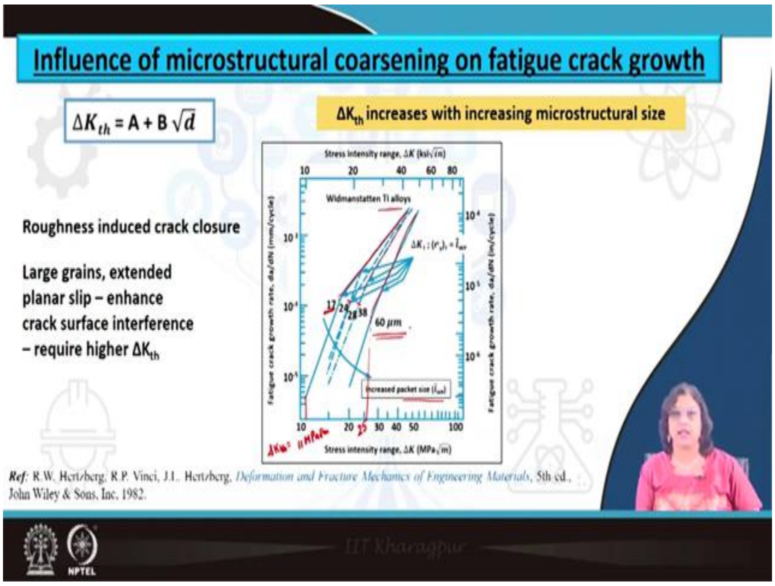

Influence of microstructural coarsening on fatigue crack growth

$\Delta K_{th} = A + B\sqrt{d}$

ΔK_{th} increases with increasing microstructural size

Roughness induced crack closure

Large grains, extended planar slip – enhance crack surface interference – require higher ΔK_{th}

Ref: R.W. Hertzberg, R.P. Vinci, J.L. Hertzberg, *Deformation and Fracture Mechanics of Engineering Materials*, 5th ed., John Wiley & Sons, Inc. 1982.

So, that has a pretty much influence on the fatigue crack growth certainly. So, that means that we can aim to achieve higher and higher microstructural size so, that we can increase the value of ΔK_{th} and our purpose for the regime I have the higher value of ΔK_{th} such that the onset of the growth of the crack can be delayed.

So, even if there is a notch present, even if there is a dominant defect present, we would like to be it in a dormant condition so, that it does not grow and that can be achieved only if we have higher and higher value of ΔK_{th} and one way to achieve that is by having increased grain size or microstructural size.

Now, this is what has been shown here experimentally that for a particular titanium alloys which are having the Widmanstatten structure, we can see that as the grain or the Widmanstatten packet size increases, starting from 17 micrometer, when it has the ΔK_{th} value something like around 10 or 11 $MPa\sqrt{m}$, let us name this as 11 $MPa\sqrt{m}$ for ΔK_{th} for 17 micrometer size and for the case of 60 on the other hand, what we can see is this value is near about 25.

So, 25 $MPa\sqrt{m}$. So, from 11 to 25 more than twice the value if we are increasing the packet size from 17 μm to 60 μm. Of course, this may vary to a different numbers for different materials. But this is quite a significant enhancement in the value and let me also point this out that enhancement in ΔK_{th} by even some 10s of number is a pretty great achievement, so that can delay the crack to a large extent, fine.

So, not only that, if we look into the curves carefully, we also see that for every cases you can see that 24 is higher than that of 17 and the ΔK_{th} for 28 is higher than that of ΔK_{th} for 24 μm and so on.

So, there is a progressive increment in the ΔK_{th} value as the microstructural size is increasing and interestingly what else we can see if we are looking carefully on this graphs is that not only the ΔK_{th} but the trend of the crack growth for the regime II is also changing, the slope of the curve is changing and the slope is getting steeper and steeper for regime II, if we are increasing this Widmanstatten packet size here and the reason once again is related to the roughness induced crack closure that larger are the grains extended will be the planar slip.

So, at every point at all the grain boundaries the crack has to overcome and move on to the next grain, which is having completely different orientation than the previous one. So, that means that the slip will be also completely different for the neighboring grain and accordingly this will enhance the crack surface interference.

And that will require that needs to have higher and higher values of ΔK_{th} to overcome that barrier and to lead to the growth of the crack and that is a reason that we are seeing higher value of ΔK_{th} with increased microstructural size.

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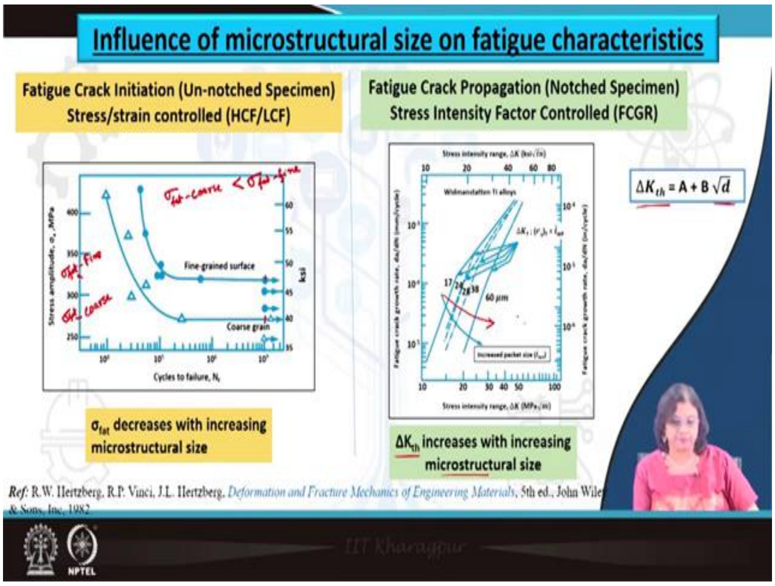

Influence of microstructural size on fatigue characteristics

Fatigue Crack Initiation (Un-notched Specimen)
Stress/strain controlled (HCF/LCF)

Fatigue Crack Propagation (Notched Specimen)
Stress Intensity Factor Controlled (FCGR)

$\Delta K_{th} = A + B\sqrt{d}$

σ_{fat} decreases with increasing microstructural size

ΔK_{th} increases with increasing microstructural size

Ref: R.W. Hertzberg, R.P. Vinci, J.L. Hertzberg, *Deformation and Fracture Mechanics of Engineering Materials*, 5th ed., John Wiley & Sons, Inc, 1982

Now, let us compare the values again once again for different kinds of fatigue. Now, we know that fatigue is of course, repeated loading, but that is not all of it when we are talking about fatigue the obvious questions that come to us is whether we are talking about notched fatigue or un-notched fatigue whether we are talking about stress-strain controlled fatigue or stress intensity factor control fatigue and most importantly, whether we are talking about the fatigue life on the basis of fatigue crack initiation or the fatigue life on the basis of fatigue crack propagation.

So, obviously, the importance of sigma fatigue or the fatigue strength and fatigue threshold strength has been seen already in the previous lecture and let us look into this in more detail. So, what the influence of microstructure what we have seen so, far on fatigue is that for the case of stress or strain control fatigue that is the un-notched fatigue or the high cycle and the low cycle fatigue actually, finer grain size is preferred. Why? Because we want to target for achieving higher and higher yield and tensile strength of the material.

That is a reason that we even do different kinds of surface treatment just to achieve highest strength of the surface. So, that the fatigue crack should not be initiated as the initiation of the crack is related to breaking the bond and which in turn is related to higher strength of the material.

And grain refinement is one of the way to achieve higher strength we are all aware of that. So, basically a fine grained surface or fine grain structure will give us a higher value of fatigue strength if we are talking about this 10^7 values of fatigue strength, you can see that for the fine grain one we achieve the fatigue strength as something like 325 MPa for example, so, this is for fine grain sized and for the coarse grain size again for the 10^7 life, we see that the fitting strength is quite less at around 275 MPa and approximate value.

So, obviously, the coarse grain one is having much lower fatigue strength compared to the fine grain one. So, σ_{fat} for coarse is much less than σ_{fat} for fine one. So, if we want to achieve higher fatigue performance, we should aim to have fine grained material such that the fatigue strength will be higher, if we are talking about high cycle and low cycle fatigue or stress-controlled fatigue.

But, so, far we have also seen that if we are talking about the fatigue crack propagation that is for the notch specimen. In that case, however, a coarser grain size or coarser microstructural sizes prefer, we have seen that how ΔK_{th} is directly proportional to the microstructural size and how ΔK_{th} increases with increasing the microstructural size is already shown in this experimental data. So, that means that there are completely 2 different kind of trend that we are seeing if we are talking about the microstructure size.

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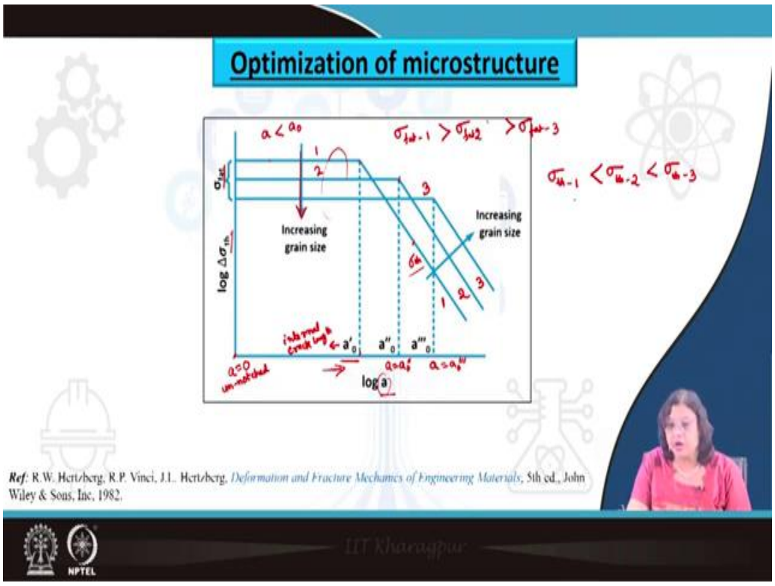

Optimization of microstructure

Ref: R.W. Hertzberg, R.P. Vinci, J.L. Hertzberg, *Deformation and Fracture Mechanics of Engineering Materials*, 5th ed., John Wiley & Sons, Inc, 1982.

And that means that we need to have an optimization of the microstructure. So, in one case, we are seeing that so, this is graph for log of σ_{th} or the threshold stress range versus a or the crack length, at this point at the origin we know that a is 0 here and that means that this is basically an un-notched component, for the case of un-notched component fatigue strength is what we are getting here, here σ_{fat}.

So, they are the sigma th does not make sense actually whatever strength that we are getting due to repeated loading is nothing but the σ_{fat} for a=0 this is however not the case if we are having a finite value of a we are getting the value of sigma th and actually the the importance of σ_{fat} will die down if we are talking about higher and higher values of a.

So, we have seen such kind of graphs earlier also when we were showing the $\frac{\sigma_{th}}{\sigma_{fat}}$ versus $\frac{a}{a_0}$ kind of graph that up to certain extent of a_0 and in this case, there are 3 different conditions are shown here.

So, this one is 1 for internal crack length of a_0', let me write this as internal crack length a_0' and for this case the σ_{fat} value is something like this the first curve here and upto certain extent upto the condition, when $a= a_0'$, we are seeing that sigma fatigue and sigma th are actually the same value and then it keeps on decreasing and basically at that point we are looking for the σ_{th} value mostly. So, here we are talking about the sigma th value we have already explained this kind of graph earlier.

Now, for condition 2 which is having a_0'', and a_0'' is higher than that of a_0'. So, for that case what we are seeing is that again the same kind of trend is being followed upto the condition when $a= a_0''$, and in this case $a= a_0'''$,.

So, that is for condition 3 and if we are looking into this carefully, what we are seeing is that the fatigue strength for condition 1 is greater than fatigue strength for condition 2 and that is greater than fatigue strength for condition 3.

So, this is what we are talking about considering only up to this part, when it is lower than, the a value is lower than the a_0 value or the internal crack. So, for this condition upto this dashed line here actually a is less than a_0, whatever it is a prime or double prime or triple prime, but at this part when the σ_{th} is of importance, there we see that so, this is now 1 and this is 2 and this is 3. So, now, we see that σ_{th} for 1 is less than σ_{th} for 2 and that is less than σ_{th} for 3.

So, with increasing grain size in this case, we are seeing a reduction in the behavior of the fatigue strength and with increasing grain size we can see an enhancement in the σ_{th} value or the threshold value.

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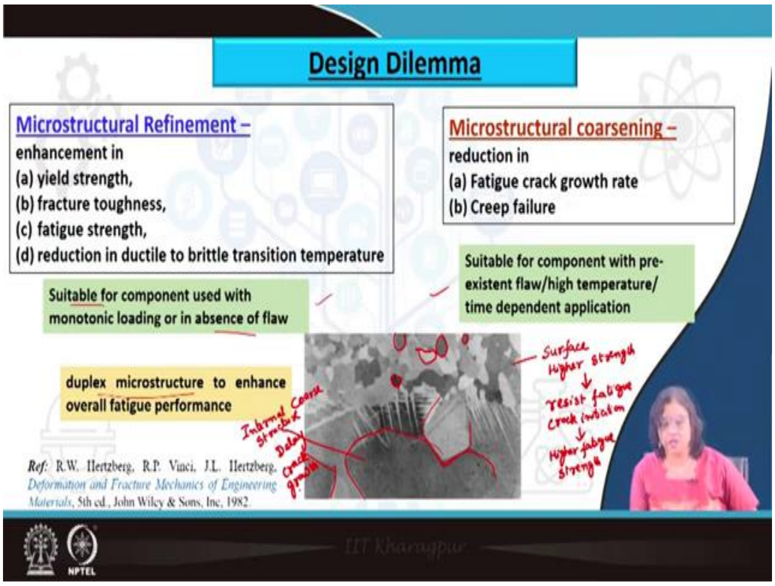

Design Dilemma

Microstructural Refinement –
enhancement in
(a) yield strength,
(b) fracture toughness,
(c) fatigue strength,
(d) reduction in ductile to brittle transition temperature

Suitable for component used with monotonic loading or in absence of flaw

duplex microstructure to enhance overall fatigue performance

Microstructural coarsening –
reduction in
(a) Fatigue crack growth rate
(b) Creep failure

Suitable for component with pre-existent flaw/high temperature/ time dependent application

Ref: R.W. Hertzberg, R.P. Vinci, J.L. Hertzberg, *Deformation and Fracture Mechanics of Engineering Materials*, 5th ed., John Wiley & Sons, Inc, 1982.

So, obviously, this is a condition which can lead to several confusion if we are talking about designing a component and that leads to a dilemma that when we are talking about microstructure refinement. So, far we have seen that microstructure refinement is one way by which we can achieve higher strength and ductility and overall higher fracture toughness.

So, that is very important way of achieving both strength and toughness enhancement. If we are able to achieve microstructural refinement, not only that, it is also expected to yield higher fatigue strength as well as ductile to brittle transition temperature also lowers down.

So, overall when we are talking about failure analysis microstructure plays a very dominant role and we often go for microstructure refining, because you can see that there are so, many factors, which can be improved, if we achieve microstructure refinement, but that is only one side of the coin.

If we flip it, then we will see that microstructural coarsening can be favorable if we are talking about fatigue crack growth rate and also microstructural coarsening is favorable for high temperature application particularly when we know that there could be creep failure.

So, that means that microstructural coarsening will be suitable for component with pre-existing flow or high temperature application or time dependent application, on the other hand, microstructural refinement will be favorable for component with either used for monotonic loading that means, that the tensile properties there are important or in case there is no dominant flow present for the un-notched component.

So, this led to the engineers the confusion that which one to choose when we are designing a component and there is a very smart way to achieve actually both the enhancement for both the cases here and there by having the duplex microstructure.

So, what do I mean by duplex microstructure is something like this, where you can see that there are the fine grains particularly at the surface you can see that the grain size is very very small here now, these are all relative size but you can make out that the grain size is very very small here particularly this is at the surface.

Now, finer grain size means that higher strength and higher strength and that to higher strength at the surface is particularly used to resist fatigue crack initiation. So, in case there is not a dominant crack present there, this kind of structure with finer microstructure at the surface will help in having higher fatigue strength.

Now, if we keep on repeating the loading condition the cyclic loading condition at some point even if whatever the final the microstructure is at some point of course, with a very high number of cycles crack may initiate now, once it initiate, we now have the bigger cracks on the interior.

So, even if the crack initiates at the surface at some point it will find it very very difficult to move through the coarser grain size because we know that the crack growth rate will be delayed. So, this is the internal coarse grain size. So, that will delay crack growth and overall we then would be able to achieve both resistance to fatigue crack initiation and even if the crack initiates after a very long number of cycles, the growth of the crack will be further delayed, which will further increase the lifecycle of the component.

So, obviously, that will lead to an overall enhancement in the fatigue performance of the material. So, this is one way of dealing with both the influence of microstructure on the different categories of fatigue by which higher properties can be achieved.

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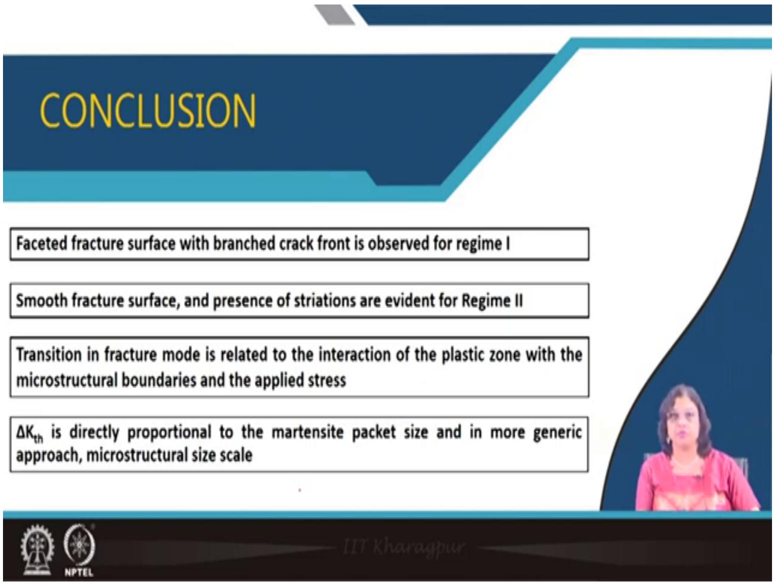


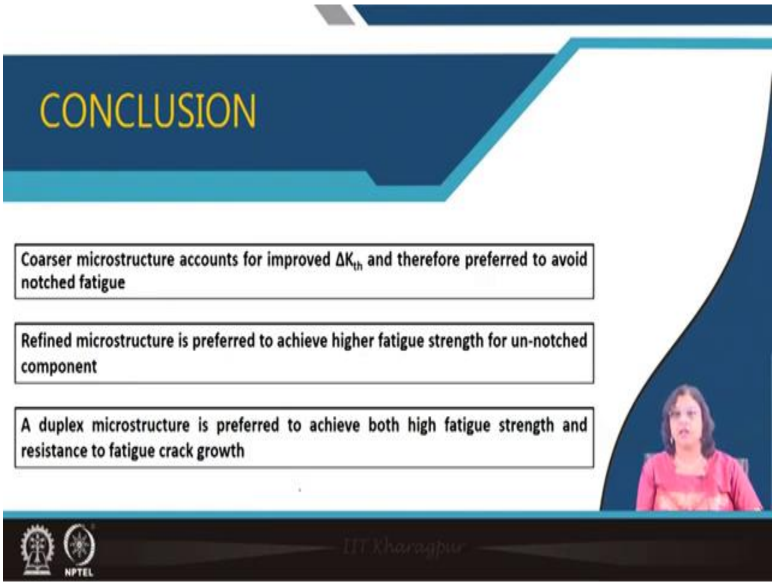
CONCLUSION

Faceted fracture surface with branched crack front is observed for regime I

Smooth fracture surface, and presence of striations are evident for Regime II

Transition in fracture mode is related to the interaction of the plastic zone with the microstructural boundaries and the applied stress

ΔK_{th} is directly proportional to the martensite packet size and in more generic approach, microstructural size scale



CONCLUSION

Coarser microstructure accounts for improved ΔK_{th} and therefore preferred to avoid notched fatigue

Refined microstructure is preferred to achieve higher fatigue strength for un-notched component

A duplex microstructure is preferred to achieve both high fatigue strength and resistance to fatigue crack growth

So, let us conclude this lecture with the following points here that we have seen that faceted fracture surface with branched crack front are observed for regime I. And on the other hand, for the case of regime II smooth fracture surface and presence of striations are noted and the transition is actually related to the interaction of the plastic zone and the microstructural boundaries.

So, this could be the grain or the lath, the colony boundaries, which anyway hinders the growth of the crack to the neighboring grain or microstructural features, but not only that, the presence of plastic zone and if that is comparable to the microstructural size that acts as a double hindrance and that requires higher values of ΔK_{th}.

And based on this, we have seen that ΔK_{th} is directly proportional to the martensite or the Widmanstatten packet size or the microstructural size in more generic form.

So, that means, that coarser microstructure will be preferred if we want to achieve higher value of ΔK_{th} and this will be favorable coarser structure will be favorable to avoid notched fatigue.

But on the other hand, we have also seen that how un-notched fatigue or the fatigue strength is related to the refined microstructure its improves, if we are my refining the microstructure and there comes a dilemma that which one to choose if we want to achieve higher fatigue performance and one of the smart way to achieve improved fatigue performance considering both the notched and un-notched fatigue behavior is through a duplex microstructure in which there is the presence of finer grains particularly at the surface which will delay or which will not allow the crack to initiate at the very first phase and even if it does the coarser internal structure will prevent the growth of the crack and in that way we can achieve a wholesome enhancement in the fatigue performance of the material.

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So, following are the references that are used for this lecture. Thank you very much.