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Mechanical Behaviour of Materials

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Lecture-01

Introduction

Hello I am Professor Shankaran in the department of metallurgical and materials engineering.

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Hello everyone welcome to this NPTEL course on mechanical behaviour of materials. I hope all of you would have seen the introduction video where I give the background of this course and the perspective students who can take this course and how they can benefit I also touched upon the broad area of this subject and its intricacies and how one would perceive about this course.

And what all one can learn in this course. Similar thing I showed in this introduction video and I have also shown some demonstration very simple demonstration taking different type of materials and then I applied some bending force and then I showed some response of these each class of materials and then I just said that the purpose of this course to understand the materials responds to the applied forces especially external forces .

So that is the primary objective so I have also showed this slide there where I have given this intended audience where you can see that students pursuing B.E, M.E, B Tech, M Tech and PhD students in the branch of materials metallurgy mechanical design and production engineering like I mentioned in the introduction video this subject requires or rather involved you know some overlapping concepts like you know.

Though it addresses primarily the materials behaviour but the kind of you know knowledge it borrows from the subjects like mechanics or strength of materials it quite connected . So, if you have mechanical background or students who have studied the strength of materials already you will enjoy this course not that others will not but you need to put in little more effort this is what I have been seeing in our classes also.

And the non mechanical background our students do not you know possess this knowledge on mechanics are simple strength of materials knowledge they need to put in little more effort to have a very smooth learning process .

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So, let me first show the syllabus though I have shared this information on the website I would like to quickly review this is the content of this course. So, if you look at it what I would like to do is before I get into the real syllabus or the subject topics I would like to spend at least 10 to 15 hours of time on fundamentals of the general material science and you know what basic knowledge probably you would have acquired by this time in this subject .

Preliminary level of ideas I want to review all of them and then we will recall all the concepts we spent more time on concepts which are very difficult you know that is a students find it then we will get into the real syllabus . So, my introduction and fundamentals will review the theory of elasticity and strength of material concepts. So, this will take minimum I think at least 5, 6 hours of classes we will cover.

And then we will talk about mechanical testing Common states of stress in real life Tension, Compression, Torsion, Bending and indentation. So, we will be concentrating more on interpretation of the data and the effect of metallurgical variables on this testing rather than our focus will be on the how to do this test and so on. So, most of the aspects we will be covering about the interpretation and metallurgical parameter how it influences the mechanical behaviour and so on .

And coming to this elasticity this is again a complete overview and review we will do which covers essentially analysis of stress state of stress at a point normal and shear stress competence shear stress competence on an arbitrary plane principal stresses, plane stress, plane strain generalized Hooke's law atomic equivalent of Hooke's law, elastic behaviour anisotropic and isotropic materials.

Like I said if any of you have already gone through strength of medical it will be a kind of redundant information for you. But I would like to cover it from the scratch because in the benefit of students will not have material students or any student to not have this background. So that they will also use this opportunity to brush up their knowledge so that it is useful. Then we come to plastic deformation.

We will cover single and polycrystalline material deformation course I will also talk about amorphous and semi crystalline materials in details then strengthening mechanisms in solids we will cover work hardening, solid solution strengthening, grain boundary strengthening, particle hardening and high temperature deformation of amorphous and crystalline materials. And then we come to the core failure concepts like creep mechanisms of creep, creep of pure metals, solid solutions, and metal matrix composites creep of ceramics and polymers and creep asymmetry and so on.

And even before that we will concentrate on fracture of solids and fracture mechanics very important topic in an engineering design. We spend a lot of time in this and we will start with all basic theories linear elastic stress field and cracked bodies. Crack deformation modes, singular stress field and displacement fields, stress intensity factors solutions, crack growth based on energy balance, Griffith's criterion for brittle fracture strain energy release rate.

And stress intensity factor equivalence, crack stability, R curves and J integral concepts, critical stress intensity factor of fracture criterion and then experimental determination of fracture toughness and nonlinear fracture, toughening mechanisms in ceramics and other materials as well. This particular syllabus we will have a complete overlap with the many engineering departments for example Applied Mechanics, aerospace, engineering design all these branches will have.

Very elaborate study in this I mean the subjects they study in this field but the focus in this course we will connect all the metallurgical variables and microstructure based you know correlations will be made. So that is where you will find a difference for that matter the entire course content also will be offered by several other departments or they all the students they also study this the one primary difference in this course.

You will always have a reference of a microstructure based or process based or you know these 2 mechanical property microstructure correlations that is the kind of focus in this course. So, it will not be completely micro structural mechanical behaviour alone. As I mentioned in the introduction video my intention is to keep a balance between microstructure and mechanics as well as the property correlations.

So, all these 3 will have equal importance in this course this is what I am trying to do let us see how we can proceed and finally we will cover the fatigue of engineering materials again very worst field in itself this particular subject again very important in most of the core engineering departments such as engineering design and aerospace, mechanical, applied mechanics everywhere you will study.

Then you will see the how metallurgically we can approach these topics? And then how we can connect our subject with best of the other approaches from the different departments. So, this will be the syllabus complete syllabus content but I will not follow any sequence what I have just listed here it is just to give you an idea of what is the content of the whole course I may go quite you know as per the fundamental how I am going to approach then this topic also will get shuffled a little bit so does not matter Yeah.

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So, these slide shows the references I believe that the people who are undergoing currently in any of this course will read this would have read this book. And I have just listed here to just to give you the perspective of what are the topics we are going to take from each of these references. So mostly I have not moved out of these references most of the content I have following only these references.

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So, we will now just begin our lecture so what you are seeing here is a very nice image but which is clearly sure depicting the spectacular failures one of the spectacular failures what you see is your ship is vertically getting split into 2 and it this is an oil tanker that fractured in a brittle manner by crack propagation around its grith. So, I will show few more majors and then we will discuss.

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Why we are looking at this, this picture all of you must be familiar with this is the pre-world War second about portion of the Titanic ship this is a remaining of the Titanic ship on the ocean bed and this is again fractured tanker which failed somewhere around 1941 this again happened around World War second the problem diagnosed that time are different nature but some of the primary cause for these kinds of failure was the usage of you know the wrong type of steel.

Basically, the steel with that Ductile brittle transition temperature which is not a characteristic. So that is something called know people learned out of these kinds of failures about design strategy to be stable the DBTT that is we will see all these concepts I am just showing these images because why this subject new, why do we need to study this mechanical behaviour of materials.

So, some of these spectacular failures are they he learned from these kinds of big failures and then try to understand materials behaviour. So, the sum of these failures which I have shown here before the one of the primary reason people recorded in the literature is, that they reverted you know points all the popped off during this accident and they all these rivets were made out of some material iron base material those days probably cast iron and so on.

So, they had some you know metallurgical property which was not characterized or which was not understood those time. So, from that point of time we will start looking at very closely how this kind of failure would have occurred . So that is how we learn from these failures so we will see one by one.

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So, other example is it is not just the huge structures but also the other types of failures. So, for example these kind of oil tankers they also subjected to cyclic loading from the ocean waves and what you are seeing here is a computer chip of course they are subjected to cyclic loading here it is a thermal cyclic loading and this particular image shows the hip implant and which also undergoes cyclic loading mechanical cyclic loading while working. So, these also some of the classical examples of you know mechanical failure.

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You will see that a big pipe which is completely broken. So, this is characterized as a Ductile failure and this is just one piece and it is considered as a large deformation. And the similar pipe which has been shattered into small-small pieces, characterized as brittle failure with many pieces small deformation .

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So, you have different type of failures and so now we will come to the main idea why do we study this subject. So, designers have machines, vehicles and structures must achieve acceptable levels of performance and economy while at the same time striving to guarantee that the item is both safe and durable. The important aspect is these 4 points designers have the challenge of keeping all these four parameters in mind before recommending any design for example, you may have design which is very good sophisticated but if it is not affordable then it is a problem. And you may have very sophisticated design but if it is not lasting for a long time then also it is a challenge. So, designers have to think about all aspects and then they need these materials properties in their hand or at least the knowledge about the materials in their hand before they recommend any materials for their design.

So, to assure performance safety and durability it is necessary to avoid excess deformation like bending, twisting and stretching of machines vehicle and structure. So, slowly we are getting into what property we are referring to. So, first we are introducing excess deformation like load bearing ability. Any structure of you under use should not undergo deformation any excess deformation you should not bend twist or stretch any structural materials.

So that is important in addition cracking in components must be avoided entirely or strictly limited. So that it does not progress to the point of complete fracture so we are introducing other word fracture now the previous point is talking about deformation. Now we are talking about fracture some of the failures we have just gone through before it is all fractures failures major failures type, we have seen spectacular failures.

So, it is better you know to avoid the cracks in the components entirely are strictly limited what do you mean by strictly limited? So, some of the flaw may be there in the component the flaw size is too small then also the material will sustain for some time till the crack you know grows into critical size. So that is what it means strictly limited later we will see in the why we study the fracture mechanics?

We will talk about damage tolerance approach like if you have a component which contains even a small flaw still sustain the services then you know that is called damage tolerance. So, we have to think about this material can withstand a critical crack size which will not cause the catastrophic failures like what we have seen before. So, what are the basic concern the most basic concern in design to avoid structural failure is that the stress in the component must not exceed strength of the material.

So, the applied stress in a component must not exceed the strength of a material. So, this is a intuitively you know everybody understands even day today life everybody knows that you know even if you have seen take a carry bag to go for shopping they know how much you can put inside that bag. So, if you overload the bag you know what will happen so, intuitively we may know all this we may be practicing it in our day-to-day life.

The same thing has to be applied in engineering design as well the stress any competent you take any structural competent moving competent you take a bus, you take a train, or you take a bicycle and then anything, anything moving or any structural membrane or any structural entity which is under use in engineering setting or even domestic setting this is a very common idea.

But we also have some other complex additional complexities causes of failure often requires further analysis that is the stresses are often present that act in more than one direction. That is the state of stresses biaxial and triaxial so it becomes a little more technical now. So, we were talking about a very general you know load or stress and strength and so on now we are talking about the direction of the stress.

It could be a biaxial or triaxial it could be more than one direction the stress is coming from more than one direction? It not necessarily unidirectional or it could be biaxial or triaxial that could be more challenging than the other one which you are the stress in a single direction. So that things become more complex so the real component may contain flaws or even cracks that must be specifically considered.

So, any competent may have you know kind of flaws and cracks. So, just before I mentioned the damage tolerance approach whether they the component or the structure and work with this flaw whether it is the flaw exists in below critical size that is the question are the stresses may be applied for a long period of time. So, there are some structures are comprehensive which are subjected to very long time you know.

So, then also you have to be cautious because we do not how that track is growing or flaws growing as a function of time that is why in most of the industries people have the periodic check once in a while, they inspect all the competence you also might have seen in the aircraft when it lands you know immediately you will see that engineers will go once the engines are coming to the stand still.

You would have seen that you know they will have for every ride you know the moment the flight lands they go and look at the blades with a torch light very careful they will see whether any damage has occurred because of any bird hider or particle hider or something like that any crack visibly observable visibly noticed. So, this is periodically done so in this case it is quite frequent like you know.

Every flight wherever it lands and takes off that examination is mandatory because you know if something happens it will be too costly but like that any every missionary and every structural member items in engineering setting will also be subjected to periodic checkup for the flows and finally the stresses may be repeated applied and removed or the direction of stress repeatedly reversed.

So, this is something come into cyclic loading the similar pattern of loading like the tides and ocean similar loading like your thermal cycling in a computer chip just we have seen or the bio implants subjected to mechanical loading while we walk, they are all periodic but you know repeated same type of stresses are repeated for a long time continuously.

And sometimes the stresses are also get reversed in direction not in not necessarily in same direction reverse direction also will cause some kind of damage we will see how these things are affecting the material behaviour. So, these are all the some of the points which addresses why we study the subject as an engineer? How one can exploit this knowledge in designing any vehicles and structures and machines and so on.