Mechanical Behavior of Materials-1
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Lecture - 31
Strengthening Mechanisms

Okay welcome back class to our course, Mechanical Behavior of Materials. So myself, Professor Sudhanshu Shekhar Singh. I am Assistant Professor in the Department of Material Science and Engineering, IIT Kanpur. So till now Professor Shashank Shekhar was talking to you about you know the source and he has already discussed about elasticity and plasticity.

And he focused on the characteristics of dislocations right, dislocation interaction, forces of dislocation, synergy of dislocations, etc. So what I am going to do, I am going to discuss about strengthening mechanisms, right? So how dislocations interact with other micro structural features present in the material in any given system, okay. And because of that, you are going to increase the strength in that particular system.

So what are the different mechanisms present which can be used to increase their strength? So we are going to discuss from today. So let us begin. Let me share the screen.

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Okay. So we are going to talk about methods of strengthening, okay. So basically suppose I gave you a piece of aluminum, okay pure aluminum and I ask you, hey can you increase the strength of this piece, this piece of aluminum, right? So what can you do? As a material scientist you should be, you must know what are the different methods are there to increase, to enhance the strength of this given metal, pure metal okay or say pure aluminum, right.

So there are different mechanisms to enhance the strength. We are going to discuss that also and other than pure aluminum suppose this is alloy. Then how do you increase the strength, right? So all these mechanisms related to increasing the strength of a given alloy, we are going to talk about it, okay. So basically what is happening, in

all the strengthening mechanisms, the dislocations are going to play a very significant role, okay.

So basically dislocations are going to interact with the microstructural features present in a given system. And these microstructural features are going to restrict the movement of dislocations and thereby increasing the strength of a given system. Professor Shashank Shekhar must have told you right, the one of the ways to increase the strength is to restrict the movement of dislocation.

And that is the crux here, right? Somehow you have to restrict the movement of dislocations and thereby increasing the strength. And that is what all mechanisms, strengthening mechanisms are based on, okay. So what we are doing? We are increasing the strength by restricting the movement of dislocations, okay. And when you do that you are increasing the strength of the material, right.

So now the question is since we have to restrict the movement of dislocation they have to interact with some microstructural feature, right? So dislocations can interact with many microstructural features and I am going to list all of them one by one. And then I am going to tell you based on the interaction of dislocation with that particular microstructural feature, what is the name of the mechanism, okay?

So you have dislocation interaction with, so dislocations can interact with different microstructural features and the first is other dislocations, okay. So dislocations can interact with other dislocations. Now in the given system you can also have grain boundary. So dislocations can interact with grain boundaries, okay.

Then if we are talking about say alloy system not pure metal right, you are going to also have solute atoms present in the alloy. So dislocations can interact with the solute atoms, okay. Now in certain alloy systems you are going to have precipitates present in the systems, okay. So dislocations can also interact with say precipitates, okay. And we have one more which is called dispersoids.

So I am going to discuss all of them, right? I am going to also talk about what are different precipitates, okay. How these precipitates form? What are dispersoids etc.

Dislocations you already know. Grain boundaries you also know, solute atoms you also know, right? So we are going to discuss all of them one by one.

Now, so if a dislocation is going to interact with other dislocations and thereby enhancing the strength of given system the mechanism is called as strain hardening, okay. Or we also call it as work hardening, okay. Now if the dislocation, dislocations are going to interact with the grain boundaries, they are getting piled up at the grain boundaries and thereby enhancing the strength.

This mechanism is called grain boundary strengthening, okay. Now the third one is solute atoms, right. So I mentioned that whenever we talk about alloys there might be some solute atoms right, in the system right? So these solute atoms are also going to interact with the dislocations and thereby enhancing the strength and that particular mechanism is going to be called as solid solution strengthening, okay.

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Now if dislocations are interacting with precipitates and thereby increasing the strength, the mechanism is called precipitation strengthening, okay. And the last one now you know right this is going to be called as dispersion strengthening, okay. So again I am reiterating right that what is happening, the dislocations are going to interact with these microstructural features present in a given system and thereby the strength of that given system is going to be increased, right?

And depending upon the microstructural features with which dislocations are interacting, the name is given like that. So if it is in dislocations are interacting with the other dislocations, we will call it as strain hardening or work hardening. If dislocations are interacting with the grain boundaries we call it grain boundary strengthening, okay? And similarly right?

If precipitates are present in a given system and dislocations are interacting then we call it precipitation strengthening. But again remember the crux says that you have to restrict the movement of dislocations to increase the strength and all these microstructural features, right, whatever I have listed here. So all these microstructural features are actually going to restrict the movement of dissertations.

And that is how we are going to increase the strength of the system, okay. So now we are going to talk about all of these one by one, but today I am going to start talking about precipitation strengthening, okay. So let us talk about precipitation strengthening first, okay. So precipitation strengthening is also called as sometimes age hardening. This is also called as age hardening, okay.

And I will tell you why this name is given as age hardening, especially for aluminum alloys, okay. So we are going to discuss about this. So now this precipitation strengthening mechanism is a well-known strengthening mechanism right, for enhancing the strength of aluminum alloys, okay. So in the lecture whatever I am going to explain we are going to mostly focus on aluminum alloys.

And then we will try to understand right, the underlying concept of this particular mechanism, again based on mostly on aluminum alloys, okay. Now suppose you are you have flown through you know aircraft, right. So aircraft, in the aircraft there are many components which are made of aluminum alloys and typically some of them are going to show precipitation strengthening also, okay.

So suppose I take a piece of aluminum or that particular component or alloy, which is used to make a component of aluminum alloy and so precipitation strengthening, okay. And I start polishing it, so that I can observe the microstructure, okay. So you start polishing it and then you etch it and then you take the sample to a, you know optical microscope, right?

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And if you do that, you are going to see a microstructure what I have shown here okay, the first one. So this is a typical microstructure of an aluminum alloy, which has been rolled and that is why you see L and S and T here. So you see L, S and T here. You are not required to go through the details, but let me tell you. So since this has been rolled, the L direction is called as longitudinal direction and T is called transverse direction and along the thickness, right?

So if it is rolled, so you have this roll plate right. So along this direction the vertical direction this is S, so we call it short transverse in the direction where it has been rolled along with it has been rolled we call it longitudinal direction L and then this direction right will be called as transverse direction, okay. And this is the typical microstructure. Here I am showing for aluminum 7075 alloys.

7075 alloys is 7 series is one of the series of aluminum alloy, okay. Anyway, he will not go into that much details about all the series, a list of series for aluminum alloy, okay. So what you see typically here is if you see in optical microscope we are going to observe grains. So you can see all these grains here, right? You can see grains here, you can see grains here and all these right, grains.

Then you can also observe these inclusions. So these dark particles what you see we call it inclusions, okay. So these inclusions in 7075 aluminum alloys are silicon rich or iron rich inclusions, we do not want them but they will be present in the aluminum alloy, okay. But what I wanted to inform here is see the scale bar here, right? So this is 300 micron meter, okay.

Now if I start magnifying right this microstructure, what I am going to observe is what I have shown here in the second image, okay. Now see the scale bar here. This is 500 nanometer compared to the scale bar in the first image which is 300 micrometer. You can see a very fine particles, right all these particles. You can see all these particles, right?

So these fine particles which you are going to observe at high magnification in aluminum alloys, we call these particles or phase as precipitates, okay. So in aluminum alloys you have to go to high magnification to observe. So this is actually a TEM image, transmission electron microscopy image, okay. And this is your optical image, okay.

So you understand the difference here, okay. So that is how that is why I have mentioned here decreasing length scale. So you are actually decreasing the length scale as you move from an image from optical microscope and then image from TEM

image, okay. So typically in the case of aluminum alloys, you might not, you are not going to observe these precipitates.

These are in nanometer size, okay. So you have to use TEM to observe this small precipitates. Now these precipitates which are very fine, they are going to restrict the movement of dislocations and since the movement of dislocations is restricted, you are going to increase the strength of the alloy system, okay.

And that is why the name is given as precipitation strengthening or precipitation hardening, okay because you are using this precipitates to increase the strength of a given alloy system, okay. So now you know the size of the precipitates are very fine, okay. Now the next question is you know how do we generate this precipitates, right?

Can all the alloy systems give you, especially in aluminum alloys can every aluminum alloy will give you precipitation strengthening, right? So we will discuss that now, okay.