Dynamic Behaviour of Materials

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Lecture – 2
Introduction to Dynamic Behaviour of Materials - II

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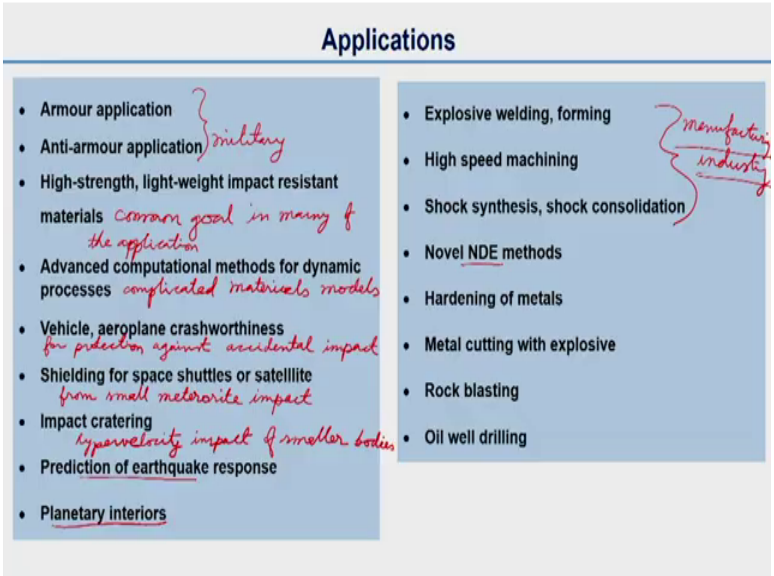

Hello everyone, in the last lecture we discussed about the difference between the deformation mechanism in the quasi-static loading and under dynamic loading. Also, we have discussed about material strain rate sensitivity and the unique failure mechanisms that a material encounters under dynamic loading conditions.

So, now, let us discuss about the applications for which we need the knowledge of dynamic behavior of materials. The application ranges from military to manufacturing industry and it also includes seismic study, vehicle and airplane crashworthiness, and even rock blasting and oil well drilling. So we will talk about these applications one by one; if not all, at least a few of them.

So, our main applications are in the military application, and then high strength, lightweight, impact-resistant materials we generally would like to develop which is a common goal in many of the applications, I mean, that involves dynamic behavior of materials.

Again, advanced computational methods for dynamic processes are to be developed for complicated material models that involve dynamic behavior of materials. Vehicle and aeroplane crashworthiness study are required for protection against accidental impact; similarly, shielding of space shuttles or satellites from small meteorite impact. So, these are the applications for which we need the knowledge of dynamic behavior of materials.

Impact cratering is the depression of the surface of earth or any other planet through hypervelocity impact of smaller bodies. So, hypervelocity does impact cratering produced by hypervelocity impact of smaller external bodies. Basically, these are the impressions made on the Earth's surface or other planets' surface.

And then, prediction of earthquake response also involve the study of dynamic wave propagation, and then planetary interiors, that is the dynamic processes inside a planet, earth or other planets, require this knowledge. And then, we will talk about the manufacturing industry, manufacturing processes a little later. And then, the new non-destructive evaluation methods have to be developed to study dynamic behavior of materials, and then, hardening of metals, some of the metals or alloys can be hardened with explosive loading, and then metal cutting with explosives, rock blasting, and oil well drilling.

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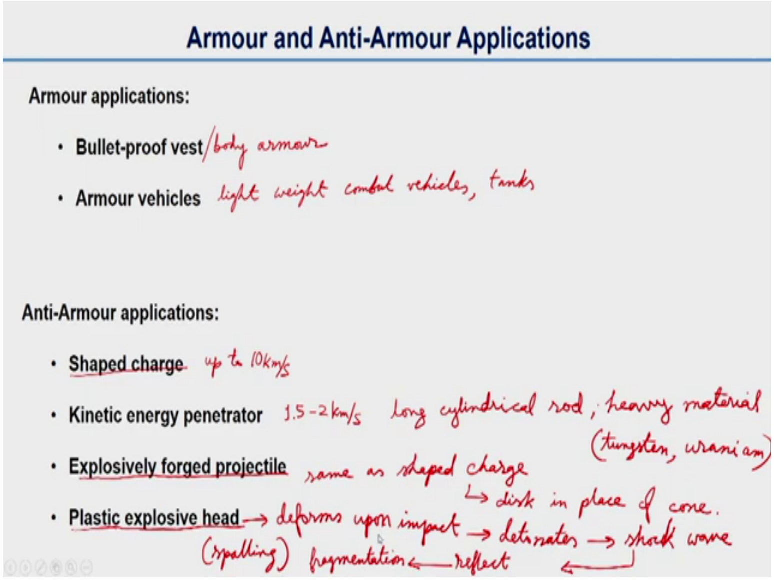

So, let us discuss about the military applications, armour and anti-armour. Armour applications involve bulletproof vest or armoured vehicles; bulletproof vest we can call it as body armour. Armoured vehicles can be lightweight combat vehicles or heavy tanks or even general vehicle for our VIPs, very important persons, or any top government officials. So, these applications need high-strength impact-resistant material.

About the anti-armour applications, a very common one is the shaped charge which can have velocity up to 10 kilometer per second; we will discuss about this in a while, and then kinetic energy penetrator and explosively forged projectile which is also same as shaped charge, and then plastic explosive head.

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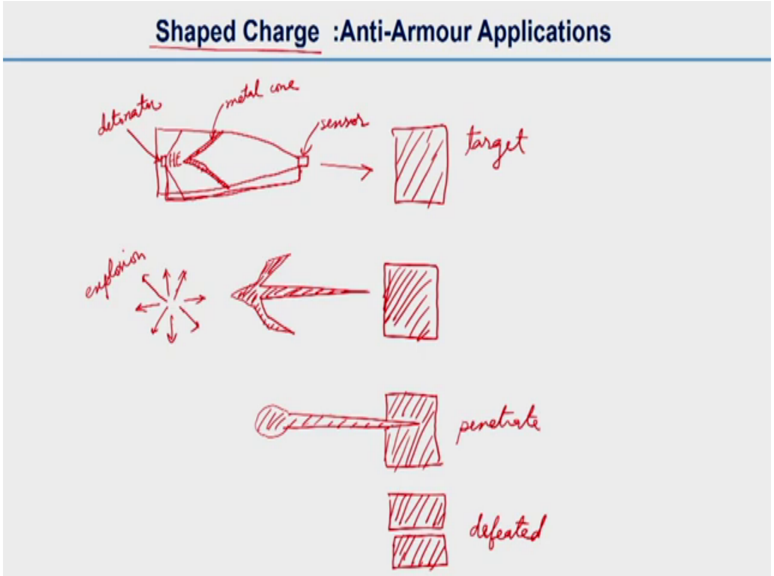

So, let us discuss the shaped charge which is one of the most common anti-armour application. So, basically, this is the missile we have, this is shaped charge. So, basically, we have a target here, this is the target, and we have a metal cone which is the main part of this shaped charge. So, we should have a detonator here and then we have high explosive. So, this is the detonator, and we have high explosive. This is the metal cone, detonator, and we have a sensor here. The sensor will be connected to the detonator.

So, when this missile will hit the target the sensor will send signals to the detonator and the detonator will explode, that means, explode the explosives in there, and then this metal cone will take a shape something like this. So, it will take a shape like this. It will transform to a long rod and then it will ultimately hit the target. And finally, there is the explosion after detonation and finally this will take a shape like this and it will penetrate the target, and then finally the target will be defeated by the shaped charge. So, this is how the shaped charge work.

And then, again, coming to the kinetic energy penetrator which has a velocity like 1.5 to 2 kilometers per second, it is a long cylindrical rod made of heavy metals, heavy materials, especially commonly used are tungsten or uranium.

Then, explosively force projectile, which is same as shaped charge, we have already discussed it, but the main difference is disk is used instead of a cone, in place of metal cone, so we use a metal disk. So, that is the main difference. And plastic explosive head, this is another one, plastic explosive head, deforms upon impact, and then it detonates, and this detonation will produce shock wave and the shock wave will reflect at the inner surface of the armour and then that will lead to fragmentation without any perforation. So, this is done with the help a mechanism or phenomena called spalling; we will discuss later about it.

So, basically, the plastic explosive head deforms upon impact and detonates and shock wave propagates and reflects back from the inner surface of the armour and that leads to fragmentation with the help of a phenomenal called spalling.

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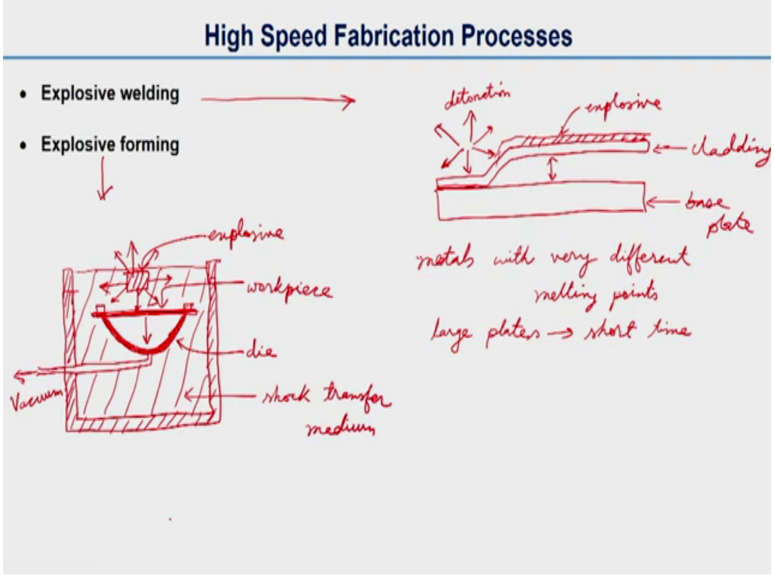

So, let us discuss about for manufacturing industry applications, high speed fabrications. We will discuss about explosive welding and then explosive forming. So, explosive welding is basically a solid state welding process where a base plate which is, let us say, some carbon steel, can be joined with a cladding, a thinner plate, something like this. This is the cladding, a thinner plate, and this is the base plate.

Let us say this is made of carbon steel and the other one is, let us say, some corrosion-resistant material, stainless steel or some other material. So, we want to join these together. So, what we do is we have an explosive layer on top of this material and then it explodes here. So, this is detonation. Here we have explosives. Basically the plates are joined together due to this explosion and eventually it will also join.

So, basically, this process can be used for metals with very different melting points. This type of joining is not possible through conventional welding processes and also one advantage is that very large plates, that means, large areas can be joined together within a very short time. So, that is one advantage. However, we need a great deal of knowledge about the explosive, how it explodes for this welding process, that is one requirement.

And we will talk about now explosive forming. So, basically we have the workpiece here with a die here. Let us say with this process you can make a boat. So, this is the boat side view and you have this workpiece. This is your workpiece. There is a sheet and you have some clamp for this workpiece and the entire setup is inside, let us say Earth's surface, it is inside. So, you have all inside. Okay, we will give some more room here.

So, this is basically for vacuum, to produce vacuum here. This is the die. This is your workpiece. So, we will have explosive in here. This is the explosive and generally the explosive is not in direct contact with the workpiece. So, we will have water in this, water as a transferring medium for the shock waves. So, shock waves will be generated. The water is the transfer medium, shock transfer m. So, basically, when it explodes this workpiece will take the shape of the die. So, this is how even some big boats are manufactured.

So, this will take, you know, the shape now, the flat workpiece will take a shape like this. So, this is explosive forming.

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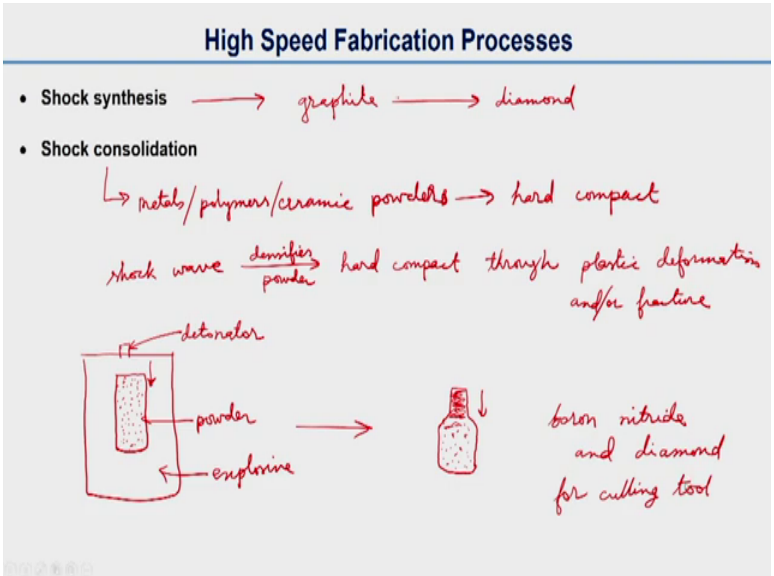

And then we will talk about another two processes shock synthesis and shock consolidation. For shock synthesis, it is used for production of diamond from graphite so we can have diamond from graphite. And for shock consolidation, it is generally used for powders. It can be metal powders, polymers, or ceramic powders to make any hard compact out of these powders. Basically, the shock wave densifies the powder to make some hard compact through plastic deformation and/or fracture.

Basically, it happens like this. Suppose, for example, if you are taking some powder in this tube, cylindrical container, we have powder here, and then you have this concentric cylinder with explosive.

So, you have the powder here and you have explosive. So, you can detonate from here, detonator. So, when it detonates from the top side the powder will transform to solid from this side. So, this way the commonly consolidated material is boron nitrite and diamond for cutting tools.

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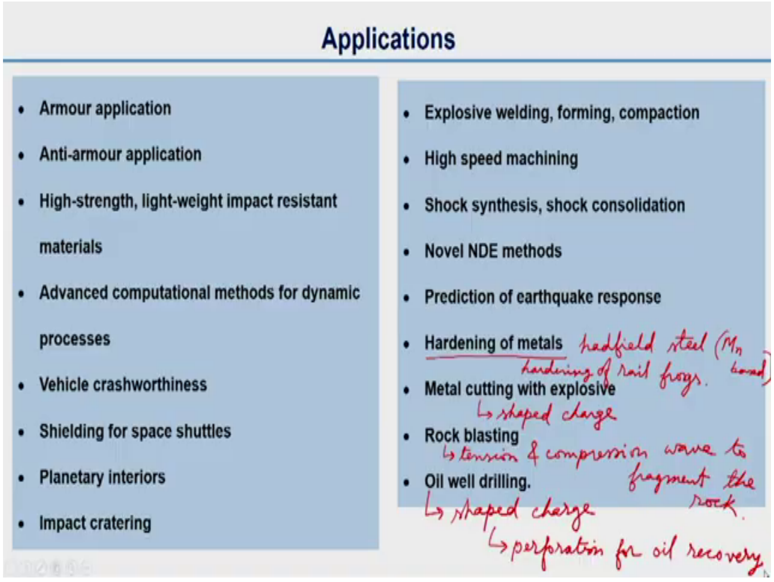

Similarly, we can have the other applications. Basically, hardening of metals is also important industry application. Shock waves are used for Hadfield steel which is a manganese-based steel. Also, another application is hardening of rail frogs, rail frog is the rail joints; it can be done with this process. And metal cutting with explosives, this is nothing but the shaped charge, and then rock blasting uses tension and compression wave to fragment the rock. This oil well drilling also uses shaped charges which is loaded down the hole and that makes the perforation for oil recovery.

So, let us discuss now about the structure of the course. What we have discussed is the applications that are basically to get the motivation why we need to study this course, dynamic behavior of materials. Now, let us discuss about the structure of the course. In the introduction part we talked about dynamic deformation mechanism and quasi-static deformation mechanisms, how they are different and what is the difference in the failure mechanisms, what is material strain rate sensitivity.

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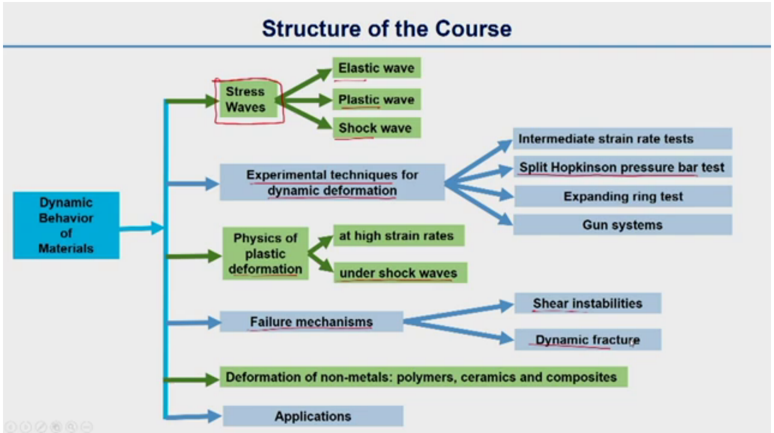

Now, then, we will talk about the stress waves, elastic waves, plastic waves, and shock waves. After that, we can discuss about experimental techniques for dynamic deformation. There are intermediate strain rate test and there are a little bit higher strain rate test.

Split Hopkinson pressure bar is the most commonly used standard test, and then expanding ring test, gun systems, and there may be a few more, we will discuss later, and then the physics of plastic deformation at high strain rate and under shock wave which is different than the normal high strain rate processes. And then failure mechanism already we have discussed in the previous lecture about the shear band and dynamic fracture. So, we will discuss about the applications and deformation of nonmetals, polymers, ceramics, and composites as well.

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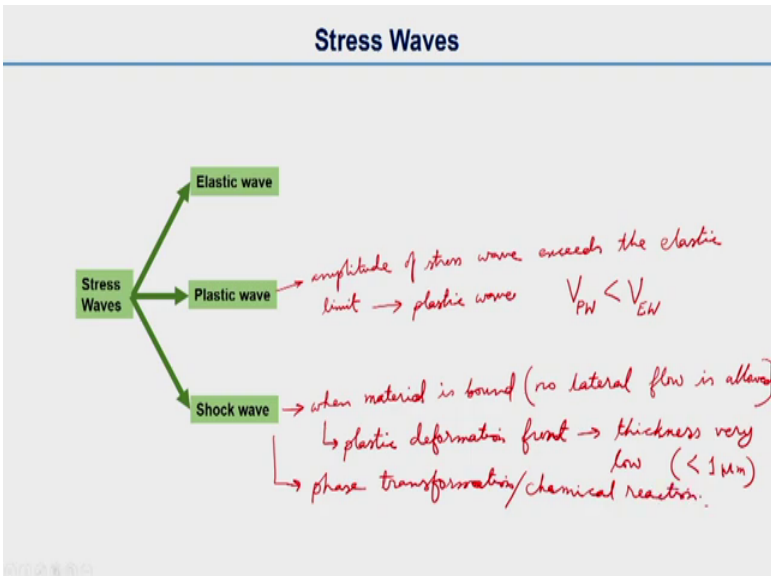

For the stress waves, the elastic waves are associated with the elastic deformation. Then, when the amplitude of the stress wave exceeds the elastic limit for a ductile material, then plastic waves are generated. Plastic wave has a lower velocity than the elastic wave. So, velocity of plastic waves is lower than the velocity of elastic wave.

And again for shock waves, when material is bound, that is, no lateral flow of material is allowed, plastic deformation front is different. So, this will lead to very different plastic deformation front which is very narrow thickness, very low. It can be even smaller than a micrometer. And also this will lead to, the shock wave will lead to phase transformations in the material and even some chemical reactions in the material.

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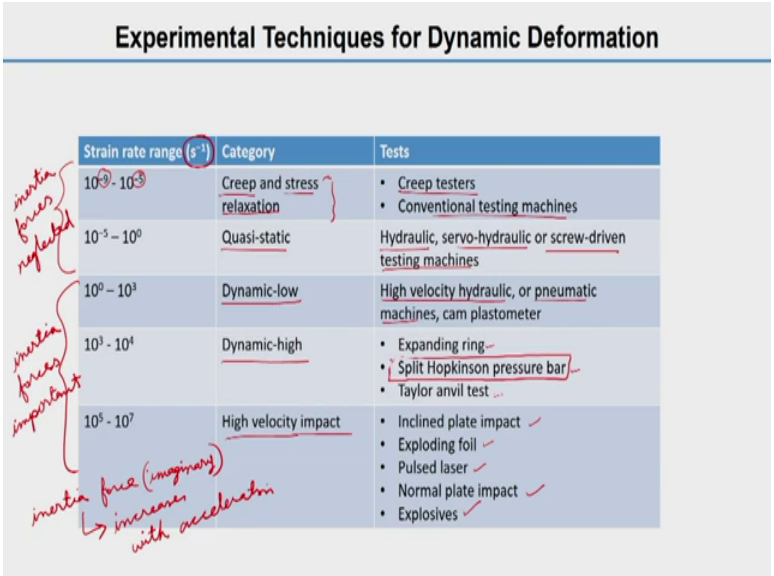

So, we discussed about the stress waves, and then after that we will talk about the experimental techniques of the dynamic deformation. So, let us see the difference strain rate ranges for different test or experimental techniques for dynamic deformation. So, as we discussed in the previous lecture, the unit of strain rate it second to the power minus 1.

We have already talked about how we can calculate the strain rate. So, in this case, the strain rate is very slow for creep and stress relaxation test which can be 10 to the power minus 9 to the power minus 5. And then comes the quasi-static test, that is 10 to the power minus 5 to almost 1, or you can take, I mean, very close to that.

And then for dynamic, we have dynamic low, we have dynamic high, and even very high speed high velocity impacts. So basically, for the first two categories, the inertia forces are neglected, and therefore, rest inertia forces are important. Inertia forces or imaginary forces that you must have studied earlier and we will discuss those later as well. So, that increases with acceleration and these are imaginary forces. So, we will discuss those later.

So, basically, for creep and stress relaxation test, we have creep tester and conventional testing machines. Then, for quasi-static test we generally use very commonly used test, we can use hydraulic or servo-hydraulic, or screw-driven testing machines. Then, for dynamic test, for low-speed dynamic test, we can have high velocity hydraulic or pneumatic machine or cam plastometer. And then for dynamic, we have expanding ring, split Hopkinson pressure bar, and Taylor anvil test.

Then, for very high velocity impacts, inclined plate impact, normal plate impact, exploding foil, pulsed laser, and then, you know, some explosive test. Basically for our dynamic test, split Hopkinson pressure bar is very important for us. This is the standard technique to obtain some stress-strain curves in the dynamic range. So, we will discuss about that.

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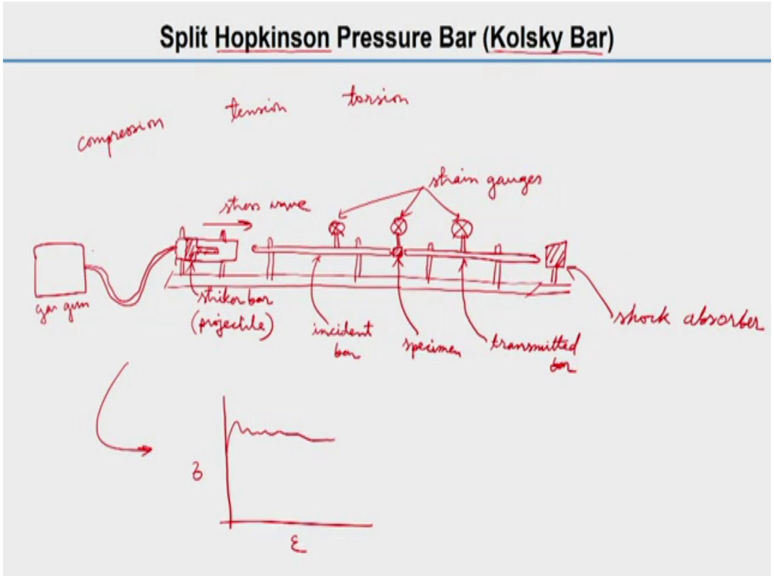

So, let us discuss a little bit in detail about the split Hopkinson pressure bar test. It is also called as Kolsky bar. So, Hopkinson is the person who developed this test but then Kolsky modified a bit. So, basically, the setup of this test is it is a very long setup, its length can be a few meters long and we have a gas gun, compressed gas will be used to drive a projectile or like we can call this a striker bar. We have this striker bar assembly. We have a striker inside it. This is what we call a striker. This is our striker or striker bar or we can call it a projectile bar.

So, we have some actually rail on support on top of which we have all these arrangements. So, we can have these supports. Here we have some, we call this incident bar, and then we have the sample here, very small sample. And then again, we have another long bar which is called transmitted bar. So, this is your striker bar, this is your incident bar. The projectile will hit the incident bar. This is your specimen which is very small. Mostly it is smaller than the bar diameter.

The common bar diameter can be 1 centimeter or even 2 centimeters, so then sample size is very small in a millimeter range. This is transmitted bar. And we will have some shock absorber arrangement here.

So, we will have some strain gauges here. Firstly, one strain gauge in the incident bar and other strain gauges stands on the specimen and then another strain gauges. So, these are strain gauges. There can be multiple strangers by the way in one bar. So, these are strain gauges.

So, basically, the striker bar will hit the incident bar. The specimen is mounted here in between the incident bar and the transmitted bar. So, basically, the stress wave will propagate through the incident bar and then through the specimen and it will transmit to the transmitted bar. Details about these tests we will discuss later. With the help of this test we can obtain uniaxial stress-strain curve for dynamic material. So, we can obtain these type of plots. So, basically, this is like the dynamic version of the very common test we perform with our universal testing machine.

And what I showed you is for compression. This is a compression test. But tension as well as torsion is also possible with split Hopkinson pressure bar. So, this tension and torsion have a little bit complicated setup. I mean, the same setup can be modified to have tension and torsion test.

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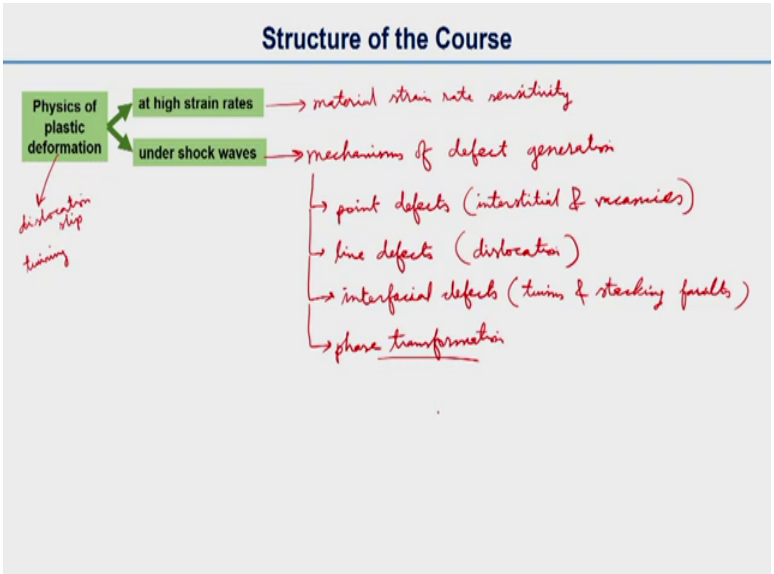

After that, we will talk about the physics of plastic deformation that we already know that plastic deformation involves dislocation motion, and then other forms of plastic deformation mechanism, may be twinning. So, basically, we need to review our basic understanding of dislocations and dislocation movement, how slip happens, how twinning happens. And then at high strain rate we will discuss about material strain rate sensitivity that we already introduced in the previous lecture.

And then, under shock waves, we will discuss about mechanisms of defect generation. Mostly, we will talk point defects, line defects, and then interfacial defects, and even phase transformations. So, point defects as you know interstitial and vacancies, line defects dislocations, and interfacial defects involve twins and stacking faults, and then we will talk about phase transformation. So, these are basically, we are talking about deformation mechanism under shock waves.

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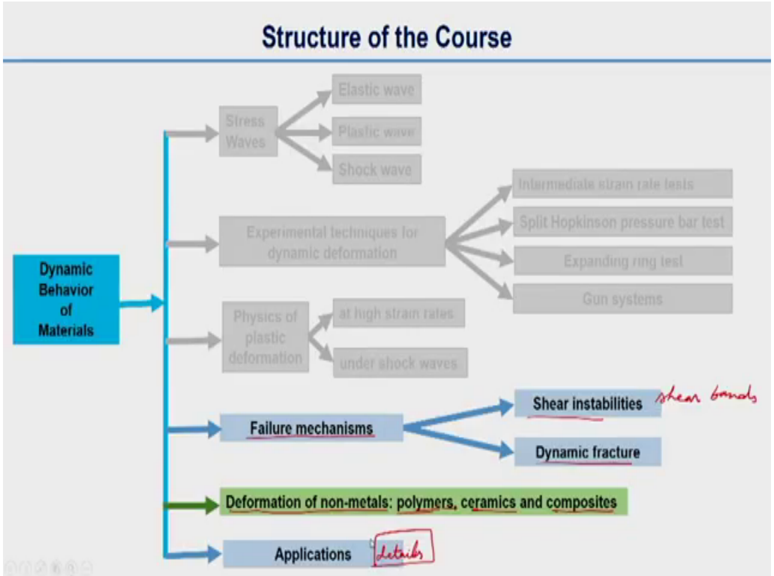

So, after that, we will talk about failure mechanisms that we have already discussed in the previous lecture, the shear bands and dynamic fracture that we have seen, the crack and brunt in dynamic fracture and crack propagation velocity has a limiting value that we have already discussed and we will discuss in details in the later part of this course, and then deformation of nonmetal is different than the metals that everyone probably knows about it.

And then, polymers, ceramics, and composites, so we will discuss a little bit of that. And then we will discuss details of applications. We will probably have one or two classes on details of applications, already we have discussed some part of it. So, with that we end today's lecture. So, we will continue in the next lecture. Thank you.