Dynamic Behaviour of Materials
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Lecture-16
Introduction to Shock Waves- I

Hello everyone, so in the last lectures we have discussed about plastic wave and before that we discussed about velocity wave, so now we will move to another chapter that is shock waves which is we discussed early and this is a part of the plastic wave founding, but we will start with the little introduction of shockwaves probably not very specific to the impact problem of shock waves. But the general shock waves we will discuss first.

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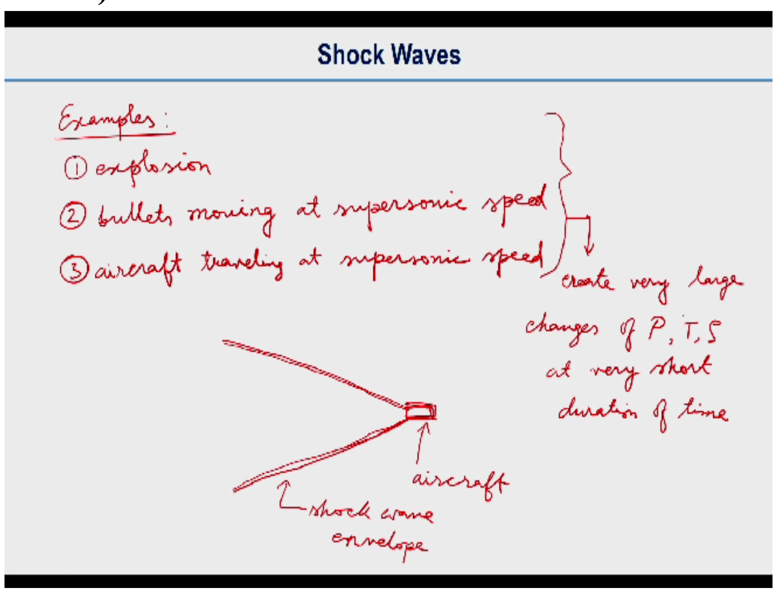

So examples of shock waves I mean what you probably heard of is explosion and then bullets moving bullets or projectile moving at supersonic speed or similarly aircraft traveling at supersonic speed. So when you talk about this bullet or aircraft moving as the supersonic speed suppose this is the bullet or aircraft we are drawing. So we can see the shock waves actually for especially for aircraft we can see the shockwave.

But for bullet probably not possible through the naked eye, but this is the envelope the produced by let us say aircraft, this is the aircraft and we can see a envelope see shock wave envelop, so similarly you will get such envelope of a bullet traveling at a very high speed. So these phenomena, so whatever it is explosion or a high-speed bullet or high-speed aircraft. So these phenomena create a very large changes of pressure I will write P for only pressure.

And pressure, temperature, density at very short duration of time, so basically we will more focus on first pressure but even for temperature and density will also have a very abrupt change at the shock wave front.

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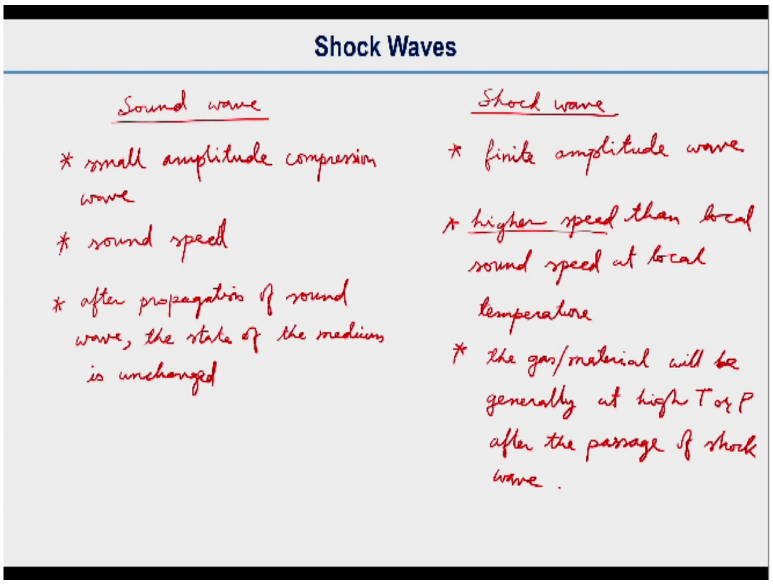

So this shock wave we can compare with sound wave, so there when we call it the sound wave they are actually small amplitude wave compression actually with their compression wave and in case of shock wave it is a finite amplitude wave. So it is very similar to the sound wave, but it is a finite amplitude that means it has a big amplitude bigger than the sound wave.

And in sound wave the speed is we call that a sound speed but here in the case of shock wave so it travels at a higher speed than sound speed higher speed than local sound speed, sound speed at a local temperature. So local means locally there what about the temperature that will decide the sound speed and in case of shockwave that has a higher speed than that. So that is one characteristic.

And generally after propagation of sound wave the state of the medium is unchanged and in the case of shock wave the material or the gas or other let us say some solid material will be generally at higher temperature or pressure after the passage of shock wave. So that we actually it is irreversible some changes happens during the passage of shock waves. So for sound wave the state of the medium will be unchanged.

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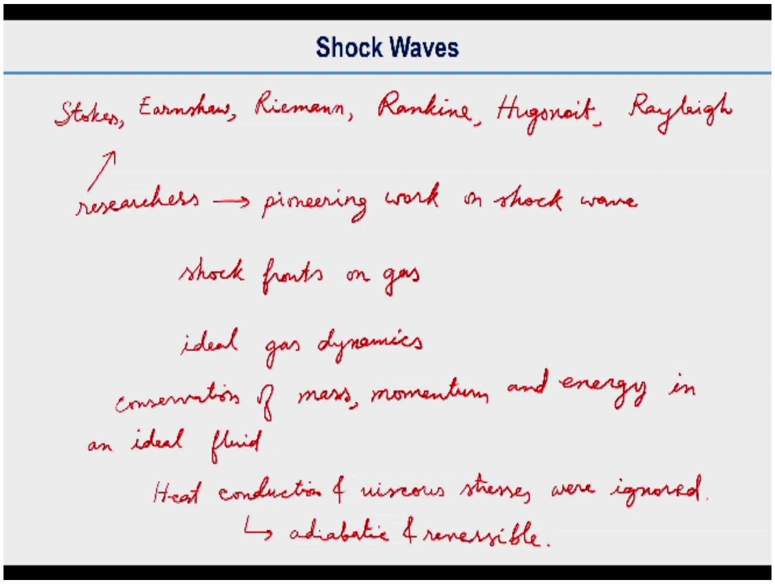

So the person's behind these, the researchers behind these shock waves research in the very early years a 100 years ago or more than 100 years ago are Stokes and then Earnshaw, Riemann, Rankine, Hugonoit and Lord Rayleigh. So these are the researchers they are the researchers who were the pioneers who did the pioneering work on shock wave**,** shock fronts on gas most of the researchers they walked on shock waves the produce in the gas.

And they used equation of ideal gas dynamics to they have used the ideal gas dynamics for their findings for their calculations. So in that time they have used the conservation of mass momentum and energy in an ideal fluid and also in this calculations heat conduction and viscous stresses were ignored**.** So viscous stresses, these are ignored that means all the time endemic changes are adiabatic and reversible.

So all the thermodynamic changes are adiabatic and reversible. So these are what we discussed is the works of the earlier researchers, so they worked that way.

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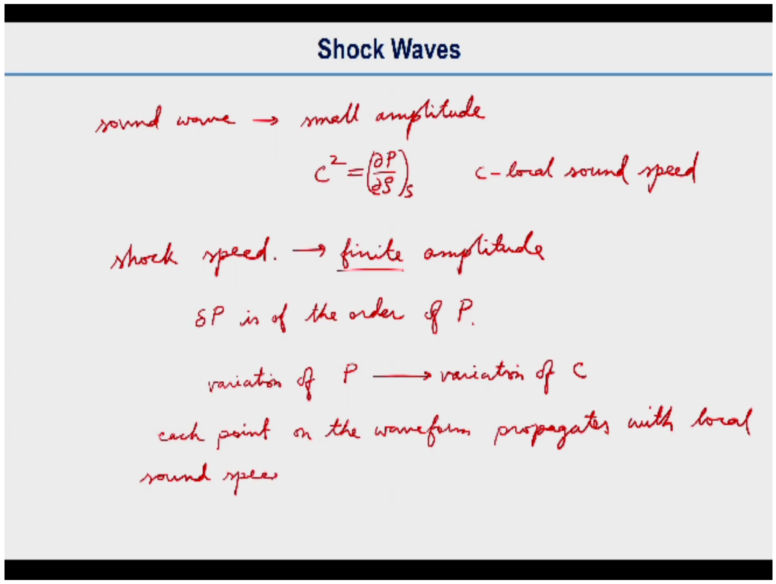

And so what will happen when this the amplitude of the compression wave is finite, so **so** in for the sound wave and the amplitude is small, small amplitude and the sound speed is related to pressure like pressure of P with respect to Rho at constant entropy we can this is the local sound speed, see the local sound speed, so we have a relation like this. But for shock also this has a finite amplitude.

The pressure change let us say change of pressure is of the order of the pressure P, so that is what we call it a finite amplitude it is the amplitude is very high. So delta P the change in pressure is of the order of the pressure P. So the variation of pressure it implies that the variation of sound speed as well, this will write C for sound speed each point on the wave form will write wave form , there is not the front that.

And the configuration of wave is the we rewrite it as a wave form propagates with a local sound speed. So that means at different points of the wave may travel with you know different sounds with local sound speed.

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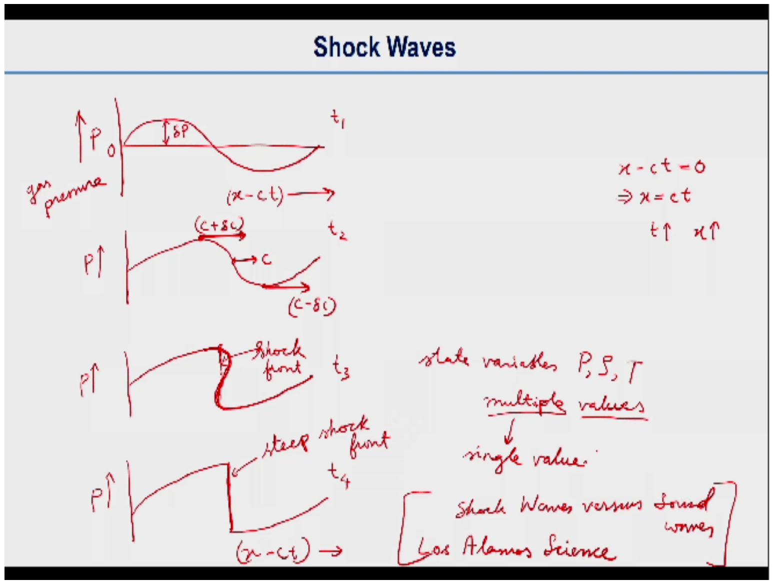

So how this pressure is changing with distance, so how this we call the stiffening happens, so this is let us say in the y-axis this is pressure, that is will write gas pressure. So this was by the way I just forgot to mention about my reference, this is not directly from the our textbooks or the reference books. This is mostly most part of the discussions are a document on shock waves verses sound waves from Los Alamos this is a report this article published in Los Alamos science from where actually I got most of the references.

So you can have a look at it that is a very brief report on shock waves from Los Alamos in of US. So what we are going to plot is so is which X - CT we thought this earlier even for our elastic we have calculations the wave equation general solution of the wave equation we have a you know function one variable we are taking as X –CT. In this case also if you think that X - CT gives a constant value.

So let us say X - CT = 0. So what will happen is, so X will be equal to CT that means weight increase in time if time is increasing, so X will increase. So that is why it is in a positive direction these wave form will move in a positive direction. So what we are seeing is here a wave form and that is let us say at time = t1. So this is the change in pressure delta P and let us say this pressure is changing.

And so this is let us say at 0 level, so now what will happen is at the time t2 as we already discussed that each point on the wave from will travel at a different speed. So what it will do is it will generate something like this, because the top point will move faster and the bottom point will move slower. So C - C + delta C and this is C - delta C.

If the let us say at a point and the middle so or otherwise I can just remove the middle line, so at a point in the middle it will move at let us C, so why it is happening we will it discussed earlier that the delta P sorry the variation of P will change the variation of will imply this variation of the C. So changes in pressure will lead to changes in the speed, at higher pressure it has a higher velocity and at a lower pressure it has a lower velocity.

So in this way if it continues so what will happen is at time t3, so at time t3 so this we will look something like this, see what will happen here is because why it is taking this shape because at the top point is moving at a higher speed and the bottom point is moving at a lower speed. So it will look like this at time t3. So and as you know X sorry the in the x axis we have X – CT. So then in this case we will get some the state variables will have a multiple values.

So suppose state variables means in this case it has pressure state variables pressure may be density, may be temperature. So in this case this is a state variable pressure. So what will happen is let us say this point and this point and a same you know same position it will take multiple values. So that is why it is this actually is not correct if you think that this predictions. The prediction means what we are doing is on the basis of that pressure the variation of pressure will vary the velocity.

But in this case we got to know that in if you do it if you predict it like that so what will happen is the state variables will have multiple values like multi value function multiple values at one position. So that is why what will happen is it is actually in reality is it will form a straight front it is that is called shock front. So what are our predictions, our predictions was that from the pressure velocity wave, velocity relations or pressure sound speed relations.

We predicted that the shape will be like this, this shape but that cannot happen because it is a multi-value and at the same position it will take multiple values of pressure or temperature or density. So that is why the in reality it will take a sharp front. So it will something like this the in reality this will take it is a vertical straight line. So this will look like this. So that is let us say at time t = t4.

So we have this shock front, so this is P here X - CT here, so this is so that is why we call this a steep wave front or we call steep shock front. So now because of this is now single value, so this is you can see that this will be now in this case will be single valued function it has only one pressure value, single valued.

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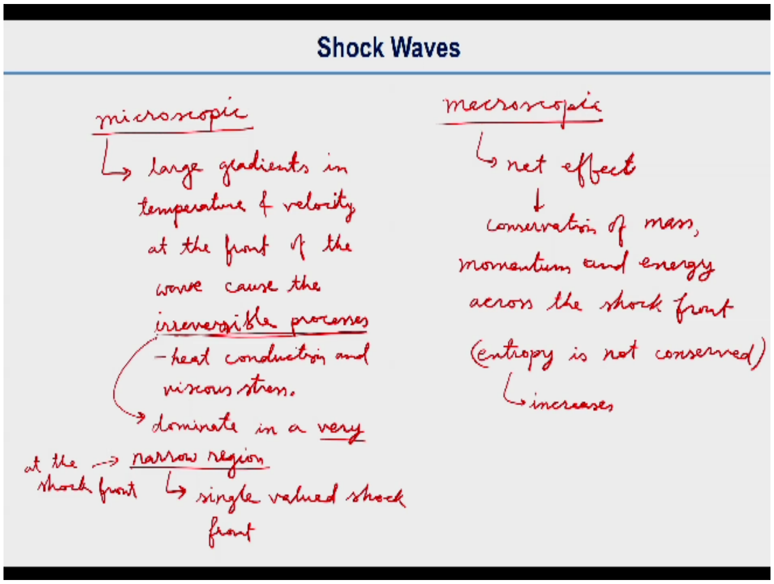

So if you see at the microscopic scale, microscopic level if you see that the large gradient in temperature, pressure, large gradients in temperature and little velocity at the front of the wave that was stiff and stiffening wave that caused the irreversible processes, there is heat conduction and viscous stress. These irreversible processes what they will do is will dominate. These irreversible process will dominate at a in a very narrow region.

So dominate in a very narrow region and this will lead to the single-valued shock front. So because of this because how it is happening these single-valued shock front. If you see here so because at a very narrow region that means that the shock front. Narrow region means it is at the shock front. So there are some irreversible processes like heat conduction and viscous stress happens and that that wave the single-valued you know shock front I mean it prevails and in a macroscopic level what happened is this is what we talked about earlier the microscopic.

Now in the macroscopic level the net effect is conservation of mass moment and sorry mass momentum and energy across the shock front. However this the entropy is not conserved, the entropy actually increases because it is related to the kinetic energy relative kinetic energy is dissipated into heat through atomic or molecular collisions. So that is why entropy increases. So we want to see in a pressure versus volume in a plot.

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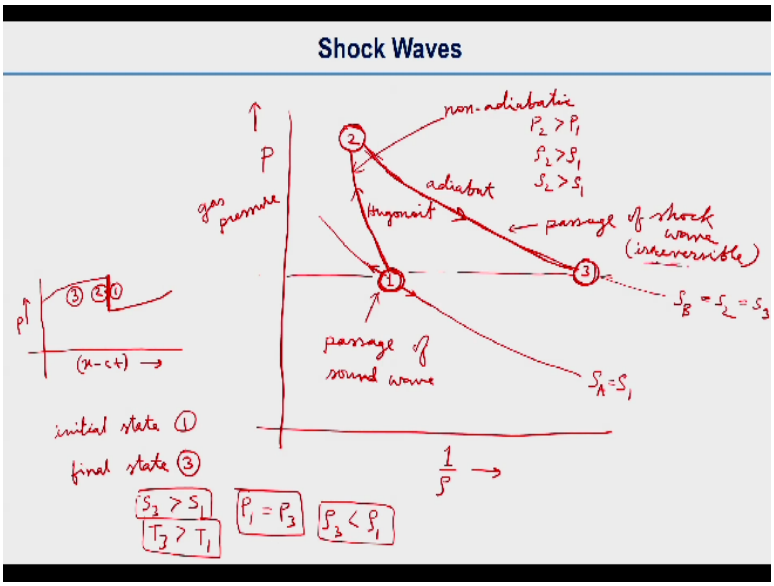

So what we will see, we will see how these reversible or irreversible changes happen for sound waves and shock waves. So this is if you have pressure in the y axis, this is gas pressure. So whatever we are talking about these are for gas and then what we will be discussing it will be on impact problem is solid material. But these concept of the shock wave will remain the same mostly it will remain the same.

So what we will we can have is we have let us say at a point at a state 1 so at a point 1, so if you draw the you know isentropic, so 1 entropy line let us say it is isentropic line, this is SA and then another one , so what we will SA and then what will this is the first position of the shock wave, so what when we made the shock wave in the earlier slide, so what is happening here is you have a shock wave front.

The shock wave front is something like this right, so when you X - CT and then P ok, so what is here happening here whatever we are drawing is number 1 is the state just ahead of the shock front let us say and further just behind the shock front so just behind the shock one suppose we have a state 2. So for that from 1 to 2 we need to draw a shock humanoid and then this is our state 2.

And then from state 2 what we can we will have an sorry adiabat line and then we can find a state 3 which is the behind the shock from this 2 is just across the this shock front. So but 3 is behind the shock front. So this will follow a adiabat and it will this is an isentropic. So let us say this is our SB. Now the shock front is non adiabatic. So when if you see at the front that means from 1 to 2, this is non adiabatic process.

So this one is at right here**,** non adiabatic and if you see this the state variables like let us say P2 is higher than P1 or you can write Rho 2 is higher than Rho 1 entropy you can see here entropy is higher than S2 is higher you know higher. So probably this in this case this is S1 and here S2. So in these entropies, so this process the passage of shock wave, after the patient of shockwave this adiabat is we can write that this is a result of passage of shock wave.

And if it is in case of a sound wave if it is sound wave so what will happen it will remain the same. So if the sound wave passes of sound wave that is not irreversible. So in this case this is irreversible, so why it is calling this irreversible because it the shock wave is starts from 1 and then it across the shock wave shock wave front it will be the state is 2. So that means it is not a isentropic the entropy is not the same.

But in case of sound wave although there will be some pressure and then the medium will be compressed and then it will by the way it is reversible process it will come back to the same position. So the after pressure the shock wave the pressure or temperature will not be high, but for passage of shock wave it will be irreversible. And so if you see what happens the our initial state of the state is 1 and our final is 3.

So if you see here initial state is 1 and then final state is 3. So in this case you can see that your entropy is higher as 3 is higher than S1. So in this case S2 and S33 are same. So S3 is higher than S1 here we showed you an even the temperature will be higher but pressure is actually probably this pressure will be same that I have not mentioned that. Actually the pressure will be same, the same pressure the P1 = P3, it will have a lower density.

So the density Rho 3 would be lower than Rho 1. So basically the what we can see that the pressure will remain same after the passage of the shock wave, but the other variables like entropy and temperature and density it will be changed and that is why it is irreversible process.

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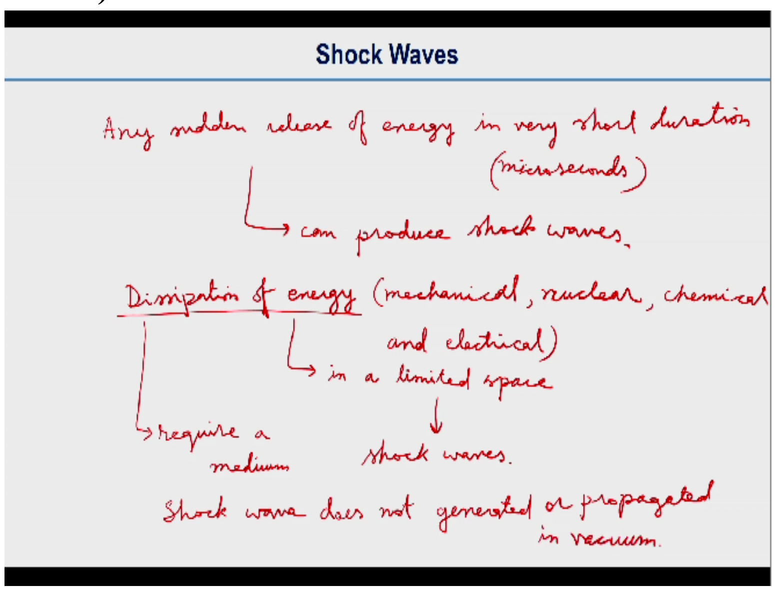

Any sudden release of energy in very short duration like in the order of microsecond can produce shockwaves, dissipation of energy the shockwave is dissipation of energy happens during shockwave. So it can be energy can be mechanical or let us say nuclear as you know nuclear energy is very much used to actually to produce shock or it can be chemical and even it can be electrical.

So dissipation of energy of any kind and but in a limited space can lead to shock waves and then as I say the dissipation of energy, the shockwave, so that is why the dissipation will require a medium for dissipation of energy. So that is why shockwave, so does not form it is not generated or propagated in vacuum.