Dynamic Behaviour of Materials
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Lecture-31
Shock Wave Induced Phase Transformations 4

Hello everyone, so, we have discussed about Graphite to Diamond Transformation Induced by Shock Waves in the last lecture. So, we will be continuing this discussion especially we will talk about today about the melting and solidification associated with Shock Wave.

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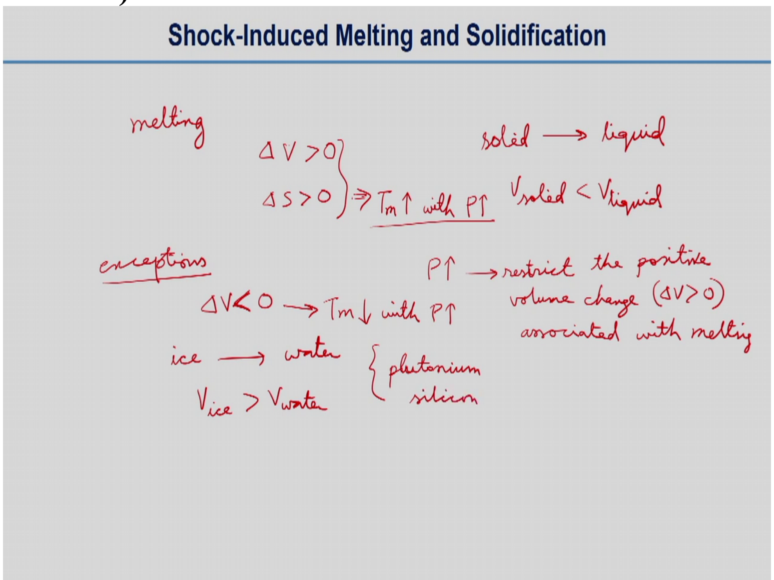

We know about this melting for most of the materials. So, we know that delta V is greater than 0 that means the solid to liquid that melting in a volume of solid is less than volume of liquid so this is liquid V. So, in the case of delta V greater than 0 delta S entropy change is greater than 0 then so, this will give us that melting temperature I will write T m for melting temperature we increase with increasing pressure.

So, it happens because when pressure will increase this will restrict the positive volume change positive volume change that means delta V is greater 0 associated with melting. So, which means pressure if pressure increases, melting temperature will increase, because that, positive volume change will be restricted, but there are exceptions to this. That means delta V maybe negative in melting, very common example is ice to, sorry, ice to water.

We know that volume of ice is higher than volume of water which is that which is why this is delta V is smaller than 0 or in that case. In that case the melting temperature will decrease with increasing pressure for this case melting temperature will decrease. So, there are other examples, other examples are plutonium, and silicon. So, these 2 materials are also upon melting. So, delta V is smaller than 0.

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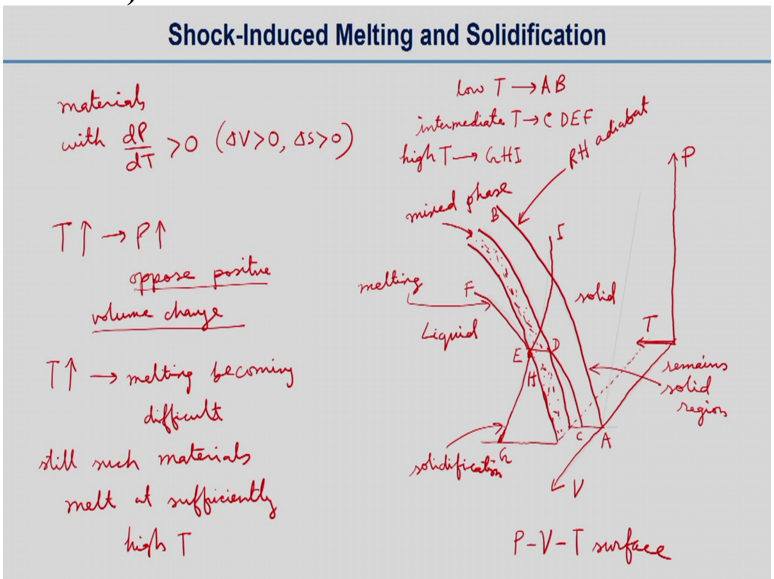

We will talk about the materials with dP dT is greater than 0 we are delta V is greater than 0 and delta S is greater than 0. So, in this case, when the temperature will increase, it means the pressure will increase and pressure will increase. That means that will oppose positive volume change. So, it seems that if T is increases, then melting more difficult, melting, becoming difficult, and because it opposes the positive volume change.

And still such materials melted a melt at a high temperature sufficiently high temperature. So, now we will discuss with a P-V-T surface about the melting in solidification, pressure volume temperature surface. So, here we will draw this; the pressure volume axes that axis is this is vertical axes to pressure and volume here and temperature on the side. So, we can draw a parallel line to the volume axis.

And then you can show that at a particular volume this line signifies these 2 lines actually signifies the mix phase region. This is mix phase, mix phase means in between liquid and solid. So, this side on the left hand side we have will have liquid and we will have solid the side. So, this is in 3 dimensional I tried to imagine this. So, and in between these on this surface, in between these 2 lines this will be mix phase, both solid and liquid.

Now, we will discuss this; what would happen if it is not the low temperature. So, let us assume that at a low temperature low T. So, at low temperature so, what will happen is shock compression, if we apply at low temperature this that Rankine-Hugonoit adiabat. So, this line is we can call it Rankine-Hugonoit adiabatic R-H adiabat. Will not intersect this mix phase region. So, let us say we can call them this line is AB.

So, low temperature this is A and B and then if we talk about little higher temperatures, so, what will happen is, this will intersect the mix phase region and this will melt so, let us assume that we can write CDEF we can join this line. So, it is an intermediate temperature. So, intermediate means high, but we will so another one which is even higher. So, the CDEF line shows that there is melting the adiabat goes through the mix phase region.

That penetrates the liquid and solid reason and if it is at high temperatures. So, you will draw a line parallel to the temperature axes. So, let us say this is the point starting point. So, what will happen at a very high temperatures, high T so, we can see that GHI line will draw it now. So, if we exact shock pressures, so, what will happen is E cross and it will go like this. So, this is solidification, so, at high temperatures.

So, this I would like solidification sorry I did not write this. So, this is GHI will be this point, but this point H and I so, that represents the solidification and for the intermediate temperature, we show this line, this had the melting here and melting and the low temperature line it is remaining the solid region remain in the remain solid region. So, this is how the solidification and melting look like in an APVT

Sorry pressure or volume temperature surface probably I forgot to tell that this point D the point D is in the atmospheric pressure and atmospheric pressure and if we again come back to these 2 lines these 2 lines which define the mix phase region that you can see that the dP dT is greater than 0. So, that means, the transformation pressure P m will increase with time T. So, this is you can see that from these thicken lines the parallel curves.

That means the transformation pressure is increasing transformation means from liquid solid to liquid transformation pressure is increasing the pressure in the on the vertical axis and T is in the from the right to left.

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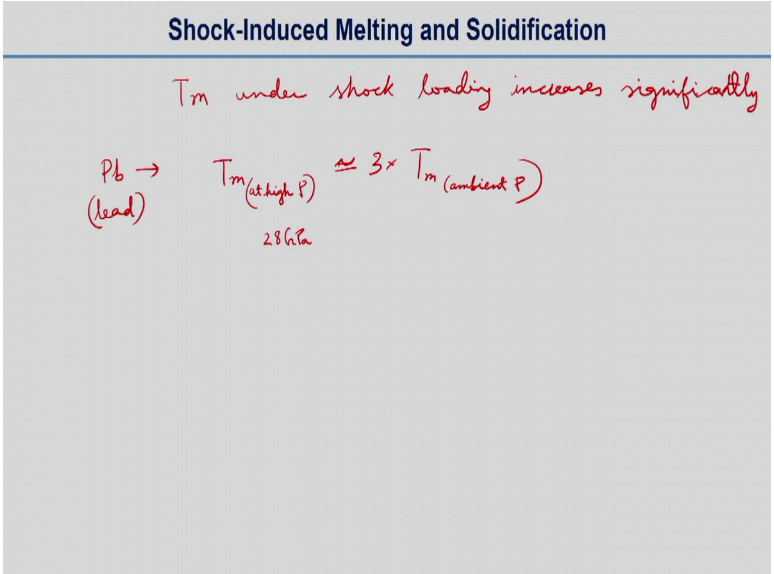

So, that is interesting just important to mention that, the melting temperature of many materials under shock loading significantly increases is significantly. For example, the melting temperature of lead melting temperature lead P b is at a high pressure shock after shock loading, let us say high pressure high P this corresponds to let us say 28 Giga Pascal and will be equal to approximately equal to three times m 3 times m melting temperature at ambient pressure.

Similarly, for other materials as well the melting temperature under shock loading at high pressure, it will be very high. So, far what we have discussed is Phase Transformation associated with compressive Shock Wave. So, now, there can be some transformation which is induced by tensile wave is not compressive wave.

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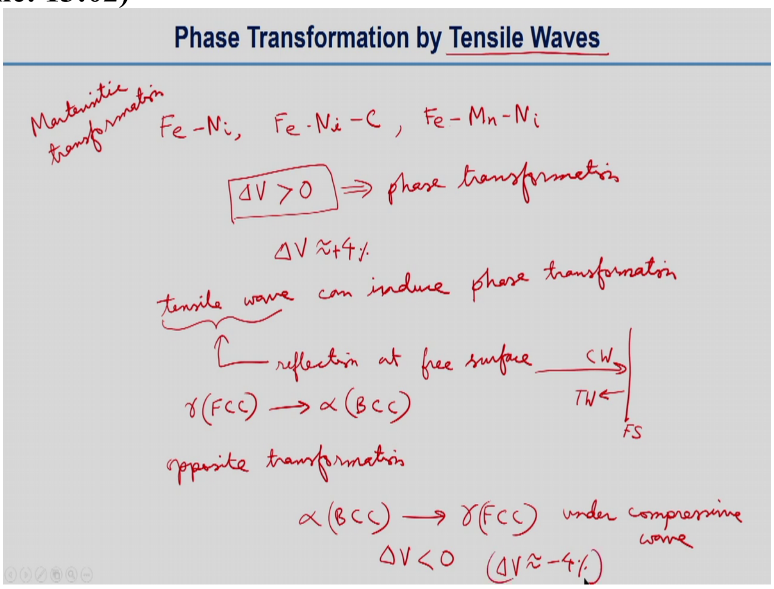

So, for example, this is in a heading we consider you can see that this is by tensile way. So, for example, the Martensitic Transformation would write Martensitic Transformation of some material, Martensitic Transformation as you know this diffusion less transformation. So, for example, iron nickel, iron, nickel, carbon then iron, manganese, nickel. So, these materials have transformation volume positive volume change will give us their Phase Transformation.

So, first of all these materials this delta V is almost equal to 4% positive 4%. So, in that case, in that case tensile wave can induce the Phase transformation that Martensitic Transformation in the case of these materials as we have already discussed many a few times. That tensile we can be produced by reflection of compressive wave at the free surface. So, if you have a free surface and your compressive wave.

Where we will go, and then will come back and that will be probably a tensile wave. So, this is I will write FS is free surface. So, tensile wave can be generated reflection of compressive Shock Wave that the free surface I would just write reflection at free surface okay. So, for these materials especially gamma phase which is FCC can be converted to can be transformed to alpha phase which is BCC.

Which is that means a positive volume change and opposite transformation can also happen opposite transformation or inverse transformation. So, that means, if the material is already where the Phase Transformation happened to alpha phase. Then alpha 2 gamma Phase Transformation can happen under compressive wave why it is compressing here because delta V in this case will be less than 0 probably delta V will be again is close to minus 4 percent the volume change is negative here.

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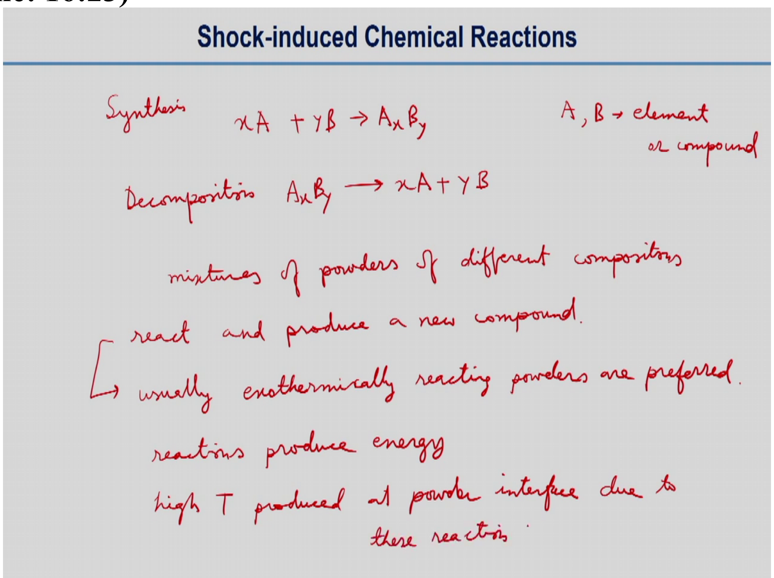

So, we will discuss now about the chemical reactions. So, as you know that there are some synthesis, synthesis reactions or decomposition reaction can happen under the shock loading. So, basically there are 2 types one is synthesis, one is decomposition. So, what we can see is the synthesis reaction is like xA + yB will be A x B y where A and B can be element or compound and then decomposition is if it is a compound A x B y.

It can decompose into xA yB just a reverse for mixtures of powders Suppose, we are having some synthesis under Shock Wave, so, the mixtures of powders of different compositions can react and produce a new component sorry new compound and usually in this case of them the reactions usually exothermically reacting powders are preferred, to these reactions produce energy and hydrate pitches produce at the order interface and high temperature produced at powder interface due to these reactions.

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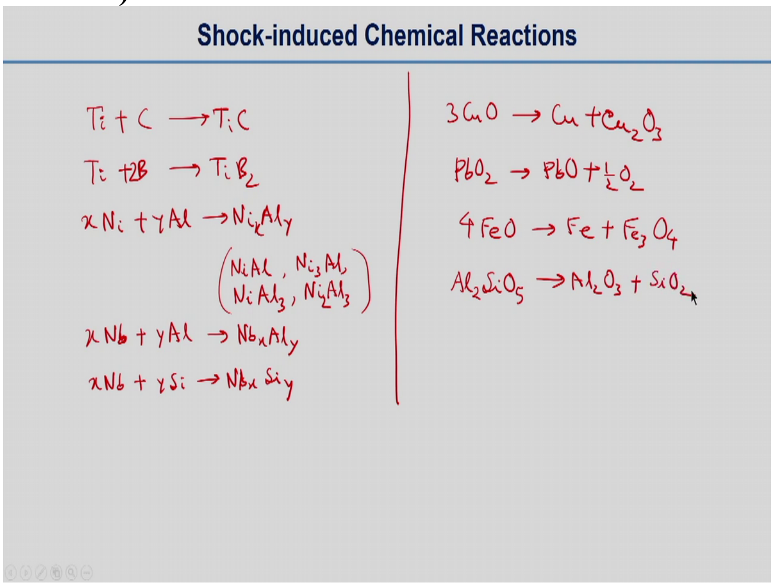

We will now see some examples of these synthesis and decomposition reactions. So, as I discuss this Isotherm reactions can be triggered by Shock Waves. So, some examples of reactions that can be caused by Shock Wave is titanium carbide, titanium bovine then nickel aluminium compound. So, nickel aluminite so why we are writing x and y here, because that can be different combinations it can be nickel aluminium, it can be a nickel NiAl 3 or it can be Ni 2 Al 3 and then even it can be Ni 3 Al.

So, these are different compounds that can form. So that is why we are writing x and y and also them they can be niobium and aluminium reaction. So, that is similar to nickel aluminite and then niobium and silicon can react together. So, similarly, for decomposition reaction, these are some examples of the competition reaction copper and then lead oxide which can take a shape like this.

So, this like composition like this and then iron oxide O 4 and then this is another compound producing alumina and silica, silicon oxide. Now, the important question is whether these reactions will be only just will be initiated by these Shock Waves or it will be completed by

Shock Wave so, when the pulse length of the Shock Wave of policies crossing the material. So, sometimes it can start just an initial or initiate the reaction and after crossing of the Shock Wave.

It can be the reaction can be completed or sometimes it can be just left as it is or that means partially completed.

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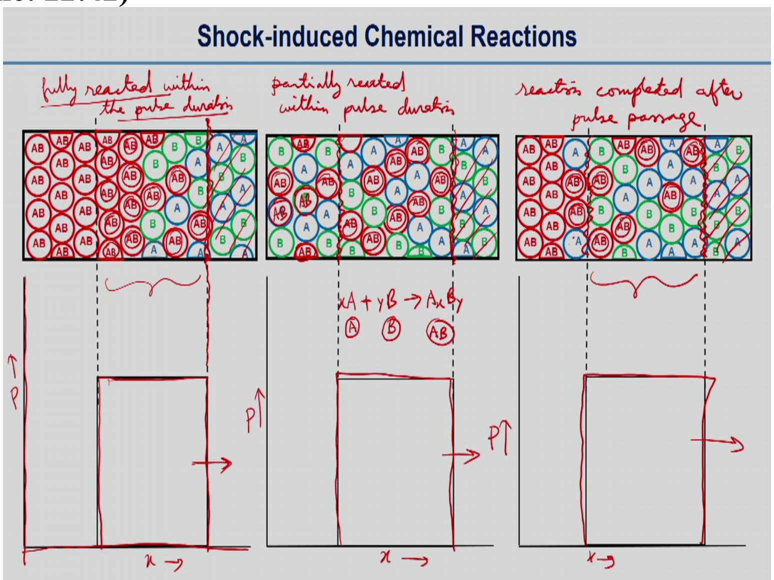

So, we will see 3 different cases here. So, first one is fully reacted within the pulse duration the second one is partially reacted within pulse duration and the third one is reaction completed after pulse reaction completed after the passage of pulse. So, what we are doing here is let us assume we are talking about xA + yB is equal to A x B y the reaction so A will we are showing like this with blue colour.

And the B particles or powders we are showing with a at the green circles and B is written inside and then AB is red colour we are showing in this and there are 3. So, if you see these whatever we have in the below picture, it has the pulse pressure and x in the x direction so, x P pulse the 3 different cases. So, this rectangle shows the pulse that you know pressure on the vertical direction and then it is moving from left to right.

So, we can understand this moving from left to right, in all the 3 cases is moving from left to right here so, it is moving from left to right. So, these are the pulse shape for the second case and for the third case, these are the pulse shape. So, here also in the first case, if we if you know see here that this line I am drawing here. So, this is the point where the pulse shape is now and the front of the palace actually shock front.

And then right hand of the shock front that means, which is still undisturbed that means, this portion let us I am drawing some shades here. So, this portion is undisturbed and, on the we can see A and B particles or powders and then after it crosses the shock front. Shock front reaches this portion and the left side that means, left side of the shock front that means the potion within the pulse duration you can see that the some AB particles are forming here.

That means the reaction started and you can see that if you go a little behind and that means within the shock pulse itself and they are all the particles are converted to AB compound. And so that means, that is what the fully reacted within the pulse duration in the second case. So, if you see the shock front is this one and then the right hand side material is undisturbed and within the shock front, that means this shock front and the back part of the shock pulse.

So if you see it is partially reacted, some reaction happened partially reaction happened and these are the particles that means the compounds AB and even after the phases, you see, there are few particles are you know converted to AB or probably we can you can probably draw a little more, it was not very clear. So, we can do one or two more here. So, this is the right direction red colour. So, it is but still it is not completed even after passing the pulse the still the reaction is not completed.

And the third case if you see this is the shock front and then on the right hand side this is undisturbed region and then in the backside of the shock front here and then this is the shock, first shock front. So, that means, this part is our pulse duration, you can see that the red colour ones these are some compound form and here if you see, after this after the crossing of the pulse in this row we have on the two let us say particles completely reacted.

But some orders are undisturbed powders are still there for example, this one and this one, but after some time after some time the all the particles will be converted to or transform to compound AB. So, this is the 3 types of reactions, chemical reaction that can happen under shock loading.

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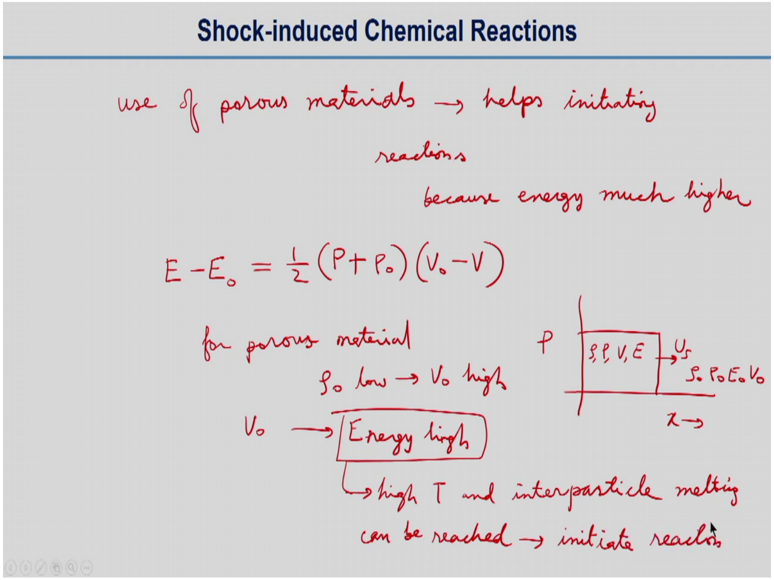

We want to show you something here. If we use of porous materials, that means porous powder for as materials. that help initiating reactions, because the energy level is much higher because energy much higher how the energy is much higher, because in earlier lecture we got to know that that the energy the equations is look like this E is the internal energy per unit must. So, P + P 0, V 0 - V.

So, where you know that this is your if it is this shock front and then you know this is the velocity US is advancing and then what is happening is Rho 0, P 0, E 0 or even write we can write V 0 these are the parameters on the in the undisturbed region. So, behind this shock front, these parameters will be let us say Rho, P, V and E So, now, we know for powder for porous materials.

For porous material to Rho 0 is low Rho is low that means V 0 is high. So, if v 0 is high that means, our energy is high energy high. So, if the energy is high that means, this will lead us sorry this, so this energy will high will lead us high temperatures, high temperatures and interparticle melting can be reached So, interparticle can be reached. So, and then that means it can initiate the reaction.

So, what we started earlier that porous materials helps initiating the reaction more than the solid material.

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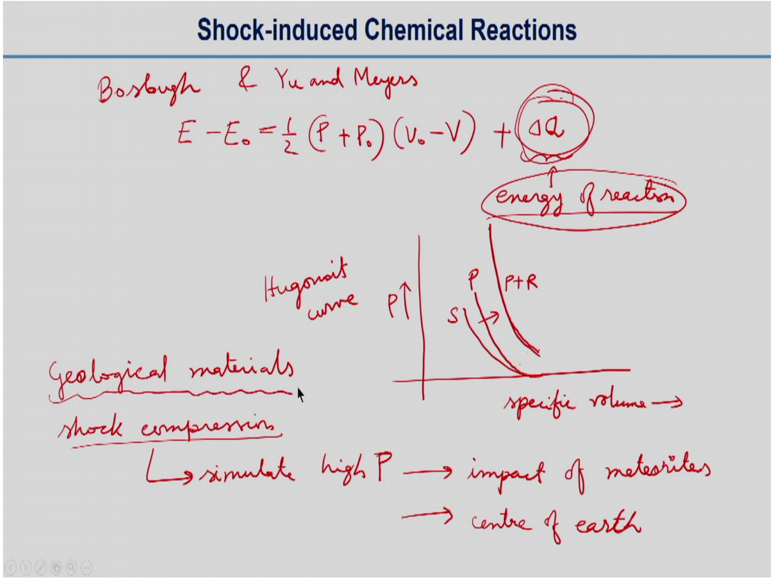

So, just to mention that some of these researchers, what they did is they just notified these equations, V 0 - V plus with a energy reaction term energy of reaction this time is So, this what it shows is that if you draw the Hugoniot curve like pressure and y axis and specific volume in x axis. So, what will happen for a solid material you are sorry maybe for solid material, I will write as S for solid material.

This will look like this, and if you talk about powder, so, if you it will look like this. So, if you add the energy of reaction term that means, that delta Q term, so, what will happen this shock Hugoniot will shift to the right so, that it this curve shows powder plus the reaction time So, that means delta Q term the researchers probably the first one is our Boslough and another publication Yu and Meyers.

They have they perform the simple thermodynamic treatment for shock compression and they added these terms and also for geological materials. So, the short compression can be used to simulate high pressure for let us say for impact of meteorites impact is a now, many people are working on it. So, for this and also for another one is for the study of center of earth for these studies.

So shock compression can be used and that is, if you are talking about geological materials. So, with that, so we will end today's lecture. So, we have discussed about Shock Wave Induce Phase Transformations. So, we have discussed some examples of it, like graphite to diamond or iron transformation from one phase to other under shock loading, and here we discuss today about the solidification and melting induced by shock wave and then other chemical reactions. So, this is the end of this chapter Phase Transformation.

So, in the next chapter, we will discuss about the experimental techniques, that those techniques which are used for use to produce dynamic deformation like the Split Hopkinson Pressure Bar, we already discussed the about that experimental technique, so, we will discuss some more techniques in the next lecture. Thank you.