Advanced Materials and Processes
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Lecture – 18
Shape Memory Alloys (Contd.)

Welcome to NPTEL. Myself Dr. Jayanta Das from department of metallurgical and materials engineering, IIT Kharagpur, I will be teaching you advanced materials and processes.

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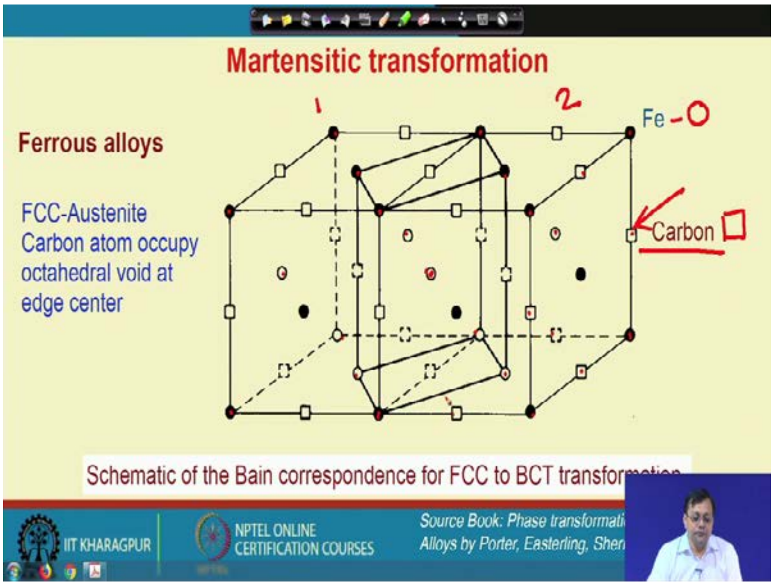

Here I show you a Bain correspondence for a face centered cubic to body centered tetragonal structure transformation. So, here face centered cubic is an austenite phase, and body centered tetragonal is a martensite product phase. Please have a look at this schematic. Here there is two FCC lattice, this is the first one, and this is the second one.

Please have a look at here. So, these are the iron atoms of the lattice 2. And here is the face centered atom. So, iron atoms are represented with a circular shape, and the carbon atoms are represented with a square shape. Now please clearly look at that. This is also a face centered atom, here is also a face centered atom, and here is also a face centered atom. Let us go to the first one. Here is also these are the iron atoms, which are located at the corner and these are the face centered atoms.

This is now opposite side of the face. Now carbon atoms here are located at the center of the edges. So, these are the edges of a FCC unit cell. And carbon atoms are located here. You can have a look in both the lattice. And now this is a face centered. And now if I join these face centered atoms, then what is going to happen? Let me change the colour. So, I took these atom here, here and here. And in the bottom also the same, and then I can join them. So, I get actually another new lattice by joining 2 FCC lattice of same structure, and same configuration.

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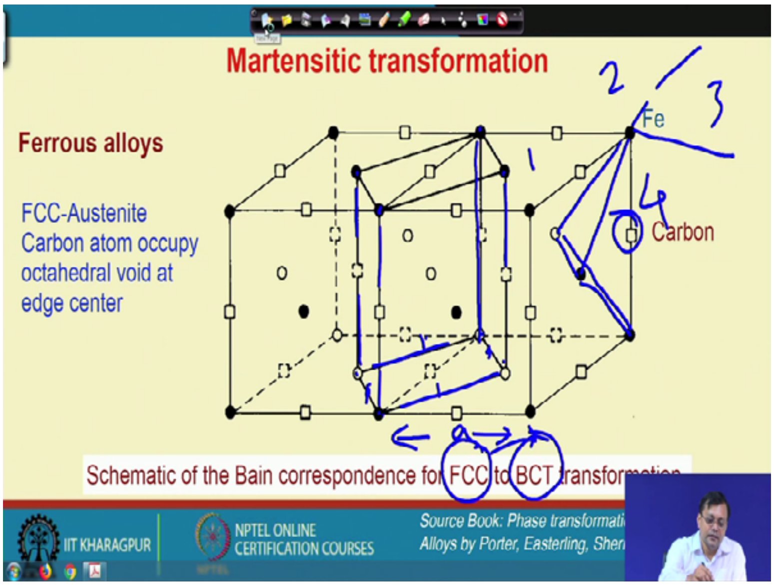

Now, here this is actually 'a', and here, this is actually the distance. So, since this distance is smaller than 'a', actually these are the same distances, where only this is the c-axis equals to 'a' so, it is a tetragonal lattice. Now carbon atom actually occupy the octahedral sites, because if you have a look why it is octahedral, and then there is we can consider 1 2 here is another one here is another one and here is another one, . So, 1 2 in the opposite side then total will be 8 actually 2 multiplied by 4. So, it will be an octahedral void.

So, in that position, the carbon atoms are present. And therefore, this schematic of the Bain correspondence shows how a martensitic transformation occur without any diffusional movement of the atoms. So, the atoms remain in the same position. However, the lattice transform from a face centered cubic to a body centered tetragonal structure, this is very much interesting and let us have a look at some other aspects.

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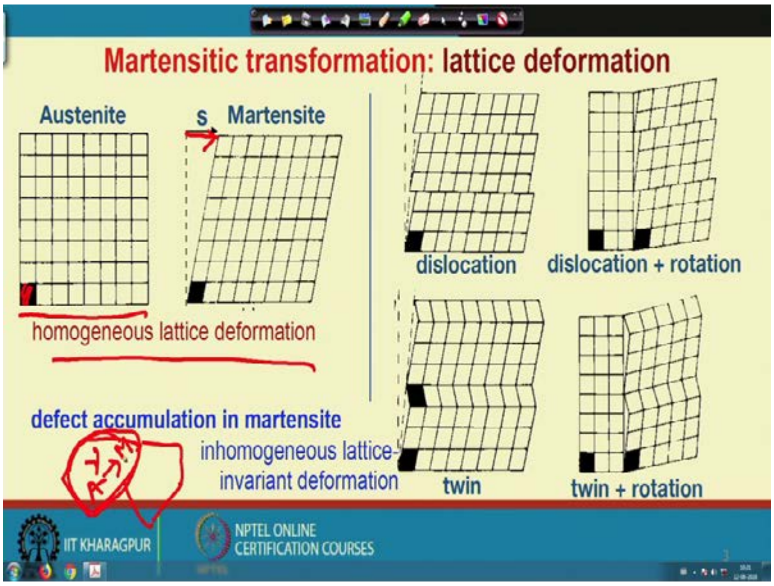

During vector analysis I have told you that there is many different invariant shear involved in the process, and twinning necessarily to be formed during martensitic transformation.

So, here I first show you a schematic of austenite lattice. So, this is the austenite lattice, a small cell is shown here which looks like the square. And for martensite to form I have given a shear which is a homogenous lattice deformation, here which is represented by an S vector. This is the net amount of the shear that is involved in this process. However, such shear, we have seen in our last class, for a single crystal how sample bend, by this martensitic transformation. However, if we have a polycrystalline grain, and this grain is austenite, and it is going to transform into martensite. Then it has to be accommodated within that region, and we need to introduce some defect inside it so that the lattice strain or invariant strain has to be accommodated.

And for that, same amount of this vector we can split into local domain in this way by introducing some dislocation. How is this process? I take the same lattice, and I simply pass some dislocation here, here and also here. So, if dislocation pass from here to here then definitely. I will get such a step, isn't it? And so, in a very small domain by passing some dislocation, I accommodate the total shear strain in this lattice.

So, dislocation is a good lattice invariant deformation process for martensitic transformation; please remember, that this dislocation we are talking about it is not in the austenite phase it is inside the martensite phase. Now let us have a look to some other invariant strain which is commonly known as twin. So, twin looks like a mirror like plane of the parent lattice. Now during this austenite to martensite transformation, this large shear can be accommodated into small domain by this way that here is the twin.

So twin you can see this is just look like a mirror like plane. Please remember, once again that this is also martensite here is also martensite. So, two lattice invariant deformation we have discussed, the third one is that we can simply rotate the lattice, so that we can accommodate the transformational strain. The third one is the rotation process, and schematically here, I have shown you that not only dislocation have passed from this austenite to martensite transformation, this is the martensite lattice; however, we have introduce some rotation into it.

Here is also a rotation is given, along with the twinning. So, here you can see the twin. So, only one defect may not be necessarily involved, in this austenite to martensite transformation, but a combination of 2 different invariant lattice deformation process may be involve into it. The fourth defect that is that may be involved in a martensitic transformation is the stacking fault.

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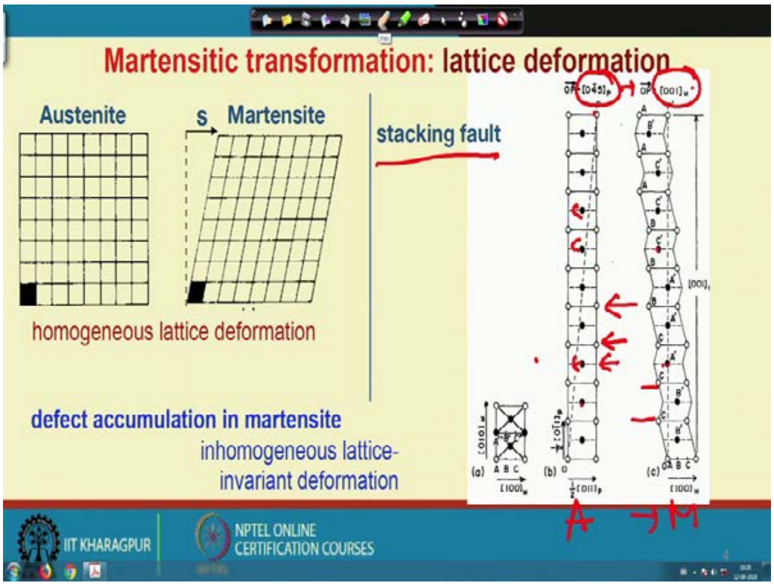

That is very interesting. And let us have a look at that. So, here this is an example of a stacking fault that has form in a lattice during austenite to martensite transformation. So, this is the martensite lattice and this is the austenite lattice.

Please have a look at this OP that is the direction here, this is the parent lattice of 045 and which transform into basically 001 of martensite, m stands for here the martensite, and there is small fault is involved in this planes. You can have a look that how the faulted positions are there. So, here if you look at the OP here, this comes into the OP here. This is the A' new position, this is the A' B', B', A' and so on. So, it basically move little bit away which comes to C' again, there is the C' which is again C' and so on.

So, by introducing a stacking fault we can accommodate the transformational strength lattice strength in a martensite lattice. So, this is something interesting and we must look at some of the examples that how this transformation involve in those systems. Here, I am talking about let us say the alloy system.

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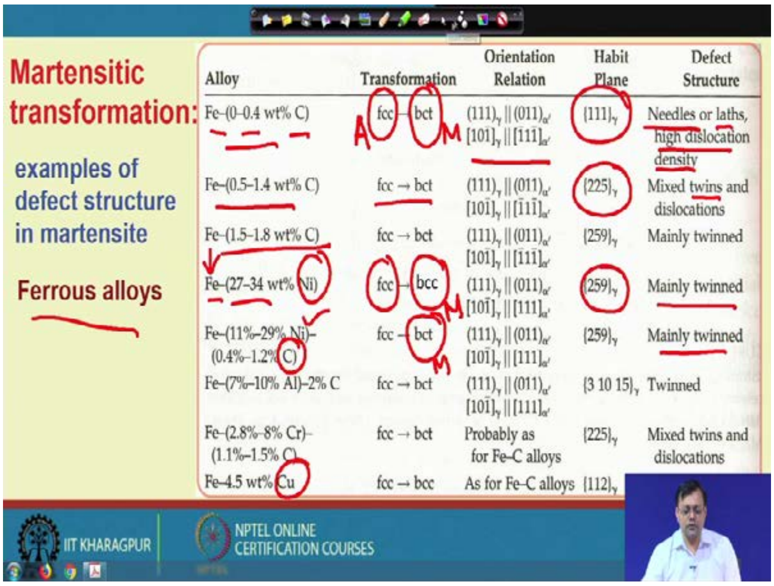

So, martensitic transformation in case of a ferrous alloy, a ferrous alloy means basically iron should be there and most commonly like carbon is present. So, let us say iron 0.4 wt.% of carbon. So, for a eutectoid steel it is 0.8 wt.%. So, in a low carbon content phase centered cubic which is the austenite, and body centered tetragonal is the martensite. And here this is the orientation relation, which of this direction and planes at the parallel to each other, and 111 of austenite is the known habit plane, and the defect structure or the substructure in the martensite involve the needles or lath type, and here it involve with the formation of dislocation.

So, the transformational strain in a low carbon martensite involve with dislocation density. Whereas, if we increase the carbon content, the crystal structure does not change in case either austenite or in case of a martensite. However, you see the habit plane has change. So, habit plane is not at all the same for all ferrous alloys. And here some twins will form along with the dislocation. Now this is the similar situation for high carbon steel. However, it is also ferrous alloy here this is iron and nickel.

So, let us say something in between 27 wt.% to 34 wt.% of nickel is present, where face centered cubic is the same phase as the austenite, where BCC is the martensite this is very interesting, right. So, austenite structure is same, but the martensitic structure is different. So, that is why I said earlier that martensitic transformation cannot be told only by the crystal structure of the martensite. So, how the transformation proceed that dictates whether it is a martensitic transformation or not. Now you see this is a habit plane and mainly twin means along with twin some other defects like dislocation and some other way from.

However once again if carbon is present along with nickel again it become body centered tetragonal this is basically the martensite, mainly twinned. And let us say in case of a iron-copper alloy, these are let us say lath and dislocations mostly present. So, we learn basically that in case of most of the ferrous alloys, even though twinning may form, but those are not so much dominating, not so much dominating invariant strain in this martensitc transformation. However, we can also discuss in case of a non-ferrous system so, I show you some of the common example of some non-ferrous system.

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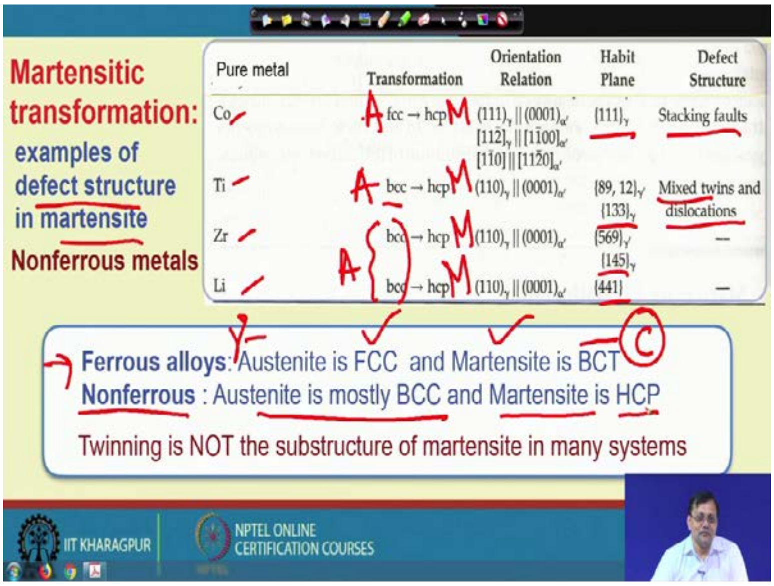

So, the defect structure in martensite in case of a cobalt, titanium, zirconium or lithium, here the austenite is the FCC phase in case of a cobalt here this is BCC, austenite is BCC. Whereas, martensite is the hexagonal close packed structure, and in case of titanium it is hexagonal close packed. In case of zirconium, it is also hexagonal close packed. In case of lithium it is also hexagonal close packed. These are all the austenite crystal structure. Now the habit plane will vary to different system, where there are some stacking fault mix twin and dislocation they also form. So, if I look at the whole literature, and a various investigation so, for people have performed we mostly see that in case of ferrous alloy since it is a γ-austenite phase so, it has a FCC crystal structure, and a martensite in case of a of a carbon containing ferrous alloys are body centered tetragonal;.

However, in case of a of iron-nickel system, where carbon is not present, because it does not bring out with the tetragonality of the structure. That is why it become the martensite crystal structure is the body centered cubic structure. Now in case of a non-ferrous system, the austenite is mostly BCC. However, there are few example of FCC also, and the martensite has a hexagonal close packed structure. So, necessarily the austenite which basically a phase transform martensitically to a martensite, yes. So, that should be the definition of austenite we should not defined by its crystal structure.

So, austenite is the phase which martensitically transform into a product martensite phase, and martensite is also transform from austenite phase. So, a twinning is also is not necessarily the sub structure of all the martensite in different system. This is also something very much interesting. So, besides twinning there could be dislocation involved, there could be stacking fault involved or there could be rotation of the lattice is also possible. So, there are so many different sub structure that are involve to accommodate, the transformational strain in case of a martensitic transformation.

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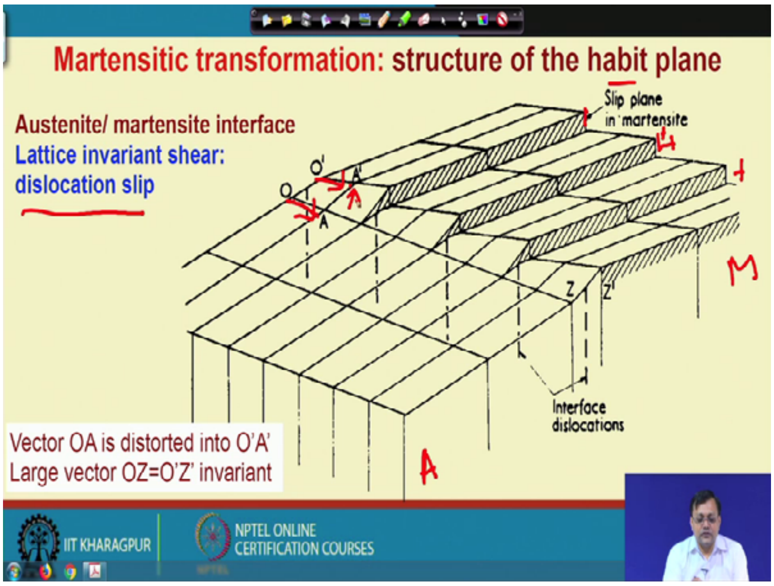

Now, let us try to look at how are the structure of the habit plane, the habit plane, I said is the invariant plane which remain unrotated and undistorted during the martensitic transformation. So, here this is a habit plane, I am going to show you in case of a where dislocation slip is the lattice invariant shear. So, if a dislocation passes through a plane, then it is for sure that it will release the strain at the surface so, there will be a zig zag surface.

Here, this is the dislocation which release at the surface. So, these are the slip plane of the martensite and dislocation has passed, and therefore, it basically shows you such kind of steps. Now here this is actually the austenite so, from austenite we are transforming into martensite and there is an interface. Now the interesting part here, that if you look at the OA vector in this particular direction, the OA when it goes to martensite it become O'A'.

And you see the direction has also little bit change because it is showing up. Now if I considered only the O and Z. This is a large vector of another large vector. And then again if I join this O to Z', then they both looks actually the parallel. So, this means in a longer or large vectors the habit plane does not change at all and so on. Similar situation we can think about in case of a twinning let us have a look how this transformation goes on in case of a twinning.

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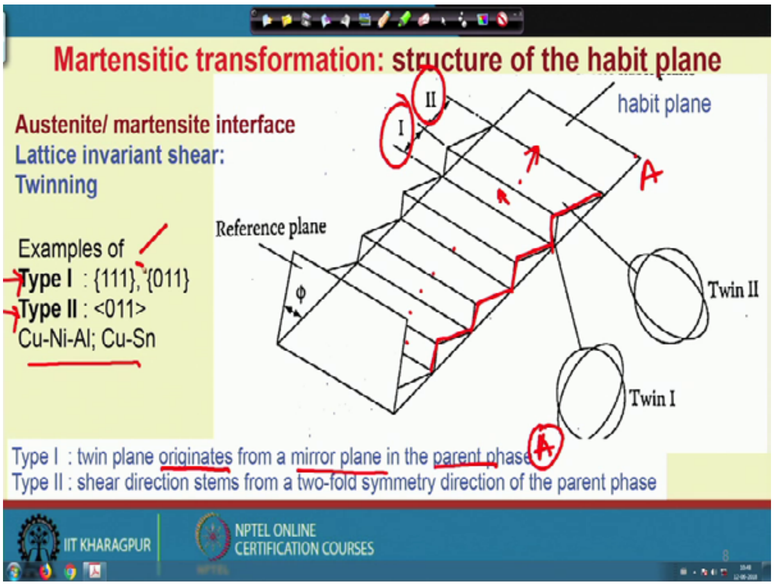

So, in case of a martensitic transformation where twinning is involved and invariant shear, you need to look at the structure from austenite into martensite.

Here, this is the habit plane and definitely here austenite transform into a martensite. The martensite accommodate the transformational strain by forming the twins. So, these are the twins, the questions is whether these are the same twins or different directions are involved in this twin. There must be different direction, otherwise this has a different direction, and this has a different direction. So, we represent here in terms of a type-I and type-II twin. So, usually type-I twin is involve and originate from the mirror plane of the parent phase, here parent phase is definitely the austenite one. However, in case of a type-II twin, where shear direction stem from the 2-fold symmetry direction of the parent phase. So, this it is important the twinning must be present, but the twinning may or the twin zones or the twin directions are different in case of a type-I twin or type-II twin.

So, there could be other types of twin also from, I show you some of the example of in case of a copper-nickel-aluminum system and copper-tin system. So, in case of copper-nickel-aluminum system here, type-I twin is from 1 1 1 or 0 1 1. And type-II twin is 0 1 1 types. So, we have seen that in case of a martensitic transformation where twinning is involve, they are not only one type of twin accommodate the transformational strain, but there could be many different types of twin which has a different direction and different planes that are involve in order to accommodate the transformational strain. So, this is a very interesting and important information to understand the shape memory effect we shall be discussed later on.

So, so for today we try to understand the different transformational strain, how it is accommodated by different defects; like dislocation or let us say like twin, like stacking fault, like rotation of the lattice. And here we also have try to look at the structure of the habit plane, and we have surveyed a large number of ferrous and nonferrous alloys where we have seen that twinning merely form where dislocation dominant martensitic transformations are involved. And whereas, in case of some other systems like non-ferrous system, where the austenite does not have a face centered cubic or martensite is not at all body centered tetragonal like ferrous alloys. However, in those cases the transformational strain could be also accommodated by dislocation or a complex twinning.

So next class, we will start with the shape memory effect.

Thank you.