Vibration Control
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Module - 7
Principles of Active Vibration Control
Lecture - 8
Shape Memory Alloy

Hi, this is Dr. S P Harsha from Mechanical and Industrial Department, IIT, Roorkee, in the course of Vibration Control, we are mainly discussing about the Active Vibration Control. And in the previous lectures we mainly discussed about the smart materials or we can say the intelligent materials, right from the piezoelectric materials, in which the actuations and sensing both are being there. We discussed about these electro rheological fluids, the magneto rheological fluids, under the action you see the electric field and magnetic field.

These fluids, which is being there you see you know like in the carrier part, the carrier oil or the non conductive oil the silicon oil rather you see. How the things can be you know like judged and how they can provide a good viscosity or the kind of we can say, the damping features there itself. And then even they can also be act as the actuator part, in last lecture we discussed about the electro and magnetostrictive materials, and even you see under the action of this electric and magnetic field, how the you know like the shape change or the shape or size changes are being there.

And also you see how they can be acted as the damping this we can say the this magnetostrictive or the electrostrictive dampers, they can also actuate the high amount of you know like the forces the high magnitude of the forces when it is being required. So, they can act as the damper and the actuator at the same time, in this lecture now we are going to discuss about the another type of material, which is also coming under the smart material named as the shape memory alloy.

The name itself speaks that if any changes are there in the shape, that can be now memorized by these alloys. And whenever you see you know like during the reverse effect or during the unloading effect, they can be reframed into their original size, the original whatever the shape or the size is there without putting any external efforts. So, you see here we are going to study about the mechanism, we are going to study about that how these materials or the alloys can be you know like applied in our vibration suppression part.

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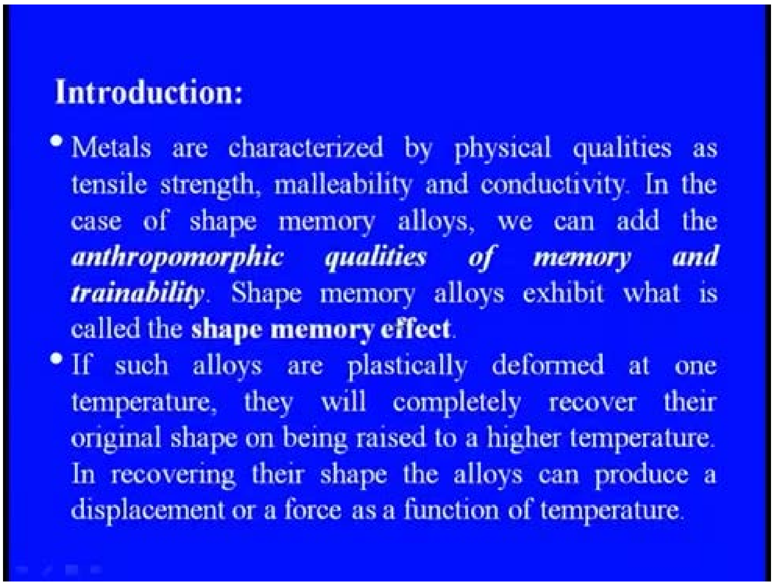

So, when the metals which we are generally characterizing you know like using say ductile or we can say brittle or various other things, just by the physical quantities like what is a tensile strengths are there, what is the you know like the compressive or the fracture toughness's are there, what is the malleability's are there, the conductivity's are there in that. But, in this case now in which we are now talking about the shape memory alloys, we need to add not only we need to talk about these strengths, along with we need to add the anthropomorphic qualities of memory and trainability.

That means, it is a very clear thing that you see here now, along with the common mechanical we can say properties, we need to now put the anthropomorphic properties together. So, shape memory alloy can exhibit what exactly we can say that what is the memorical features are there with the effect of these common mechanical properties of the material. So, if such alloys are we can say plastically deformed at one temperature remember we are talking not the elastic which is a common feature of all the materials.

But, when we are plastically deformed these materials at one temperature, they will be completely recovered to their original shape, when they are being raised to a higher temperature. In recovering their shape the alloys can produce a displacement or a force as a function of this temperature.

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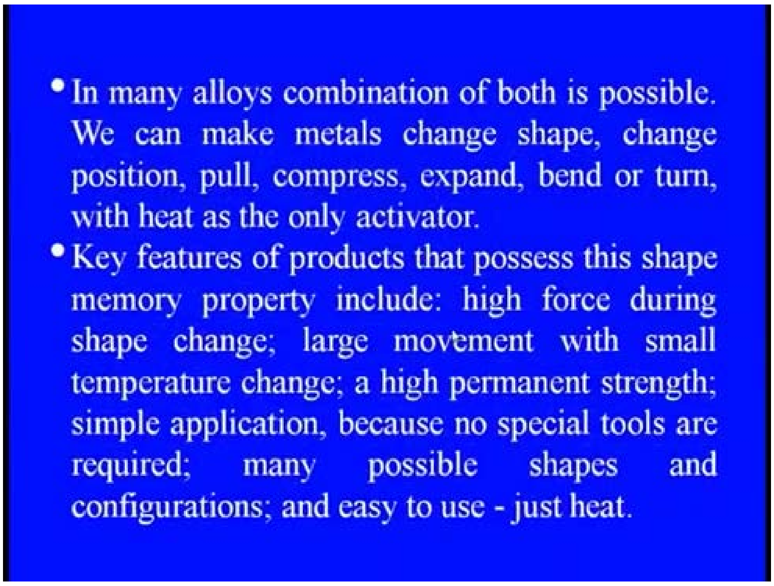

So, in many alloys we can say that the combination of both is really feasible and possible, where the mechanical strength. And you see this shape memory effect can be added together, and we can make the metal change, we can say you know like change in the shape, change in the position, pull compress, expand, bend or we can say you know like the turn with the heat just as the only activator. The key feature of the products that process this shape memory property, can be can include the high force during the shape change.

The large movement with the small temperature change, a high permanent strength where the simple applications are there you know like various things. Because, no special tools are being required and many possible shapes, and the configuration can be easily drawn up. And the important feature is this that it can be easily used because it just requires a heat the temperature part. So, that is why you see here when we are talking about say the high force requirement is there, loss temperature or the low temperature requirement is there, high permanent strength is being required there these you know like we can say the shape memory property can be straightaway included in these alloys.

So, we can say you know like in the development application of these shape memory alloys, it can provide a simple and the virtual leak proof couplings for the pneumatic or hydraulic lines. And the alloys have also been exploited in the mechanical and the electromechanical control systems that is what our requirement is, where the precise mechanical response to a small and repeated temperature changes are being the prime requirement.

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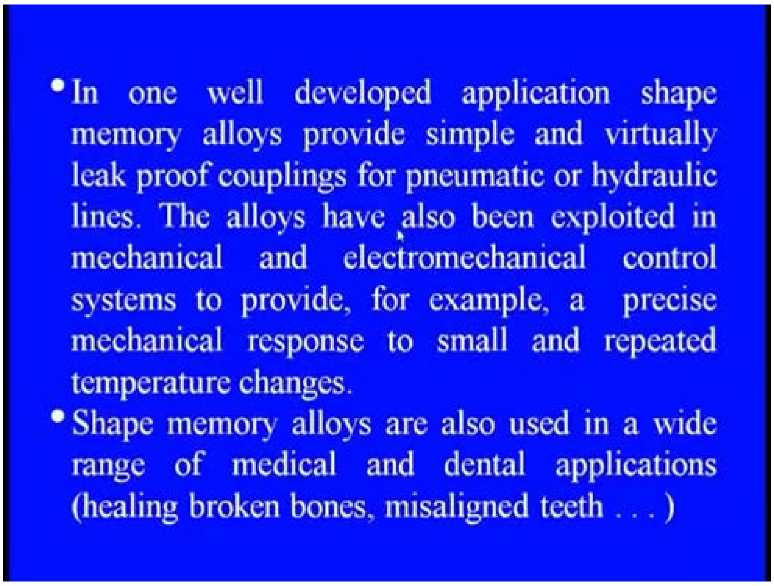

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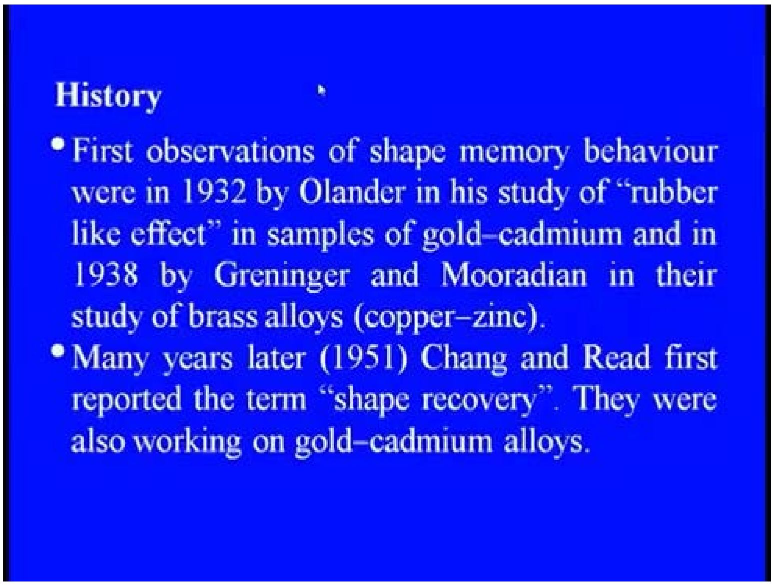

So, these alloys are also used in the wide range of mainly in medical and the dental applications, where we just want to say heal the bones the broken bones, there is a perfect use of the shape memory alloys. And even when we are just trying to align the teeth or when we just trying to the treat the teeth these materials are being used for that. So, this is what you see the basics about the shape memory alloy that what exactly is happening with the shape memory effect. And when we are you know like just inducing in the alloys, then how that can be there and what exactly the application features are there.

But, when we are talking about the history in somewhere 1932, the olander you know like the in his experimental studies he found that. That there is some kind of shape memory behavior in some of the we can say you know like the alloys, which he said that it is you know like the rubber like effect. Like he studied with these gold cadmium, the main alloy, and in 1938 later on you see here the greninger and this mooradian they also studied the similar kind of behavior, in the brass alloys like the copper zinc and all.

And in 1951 later on the Chang and read first time reported, the term called the shape recovery when they were working with the gold cadmium alloys. So, right from you see the you know like in the 1932 when the gold cadmium was there, and olander says that it is a rubber like effect in 1951 the on the same gold cadmium alloys, the Chang and read said that it is a kind of shape recovery feature in this.

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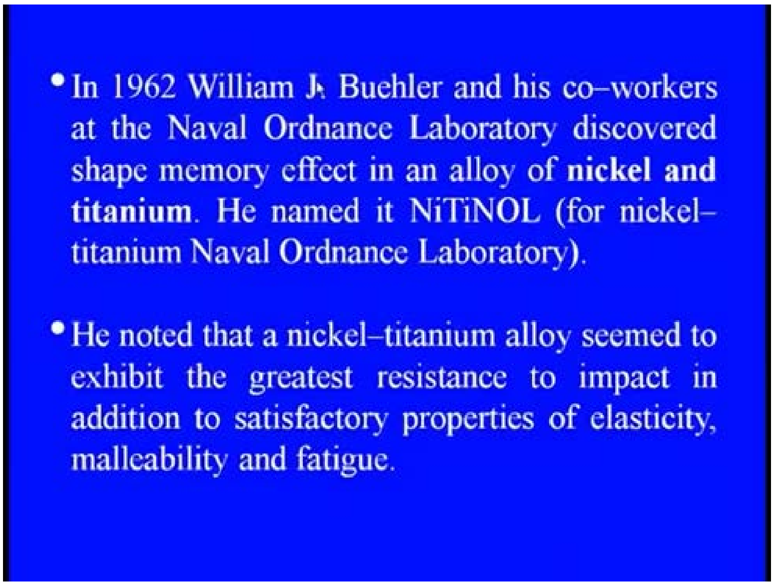

But, later on you know like in this we can say this NiTiNOL laboratory basically the naval ordnance laboratory, in that William j Buehler, and his co-workers. They simply said that when they are you know like simply discovered that the shape memory effect is quite dominating in the alloy of the nickel and the titanium. And that is why you see they said that, the entire laboratory which will be named after the nickel titanium naval ordnance laboratory.

And they simply noted that, when this nickel titanium alloy seemed to you know like when they have you see you know like working together. They have the greatest resistance to the impact in addition to the satisfactory properties of the elasticity, malleability and the you know like the fatigue features. And along with that you see here, they were simply exhibiting these you know like we can say the shape memory features together.

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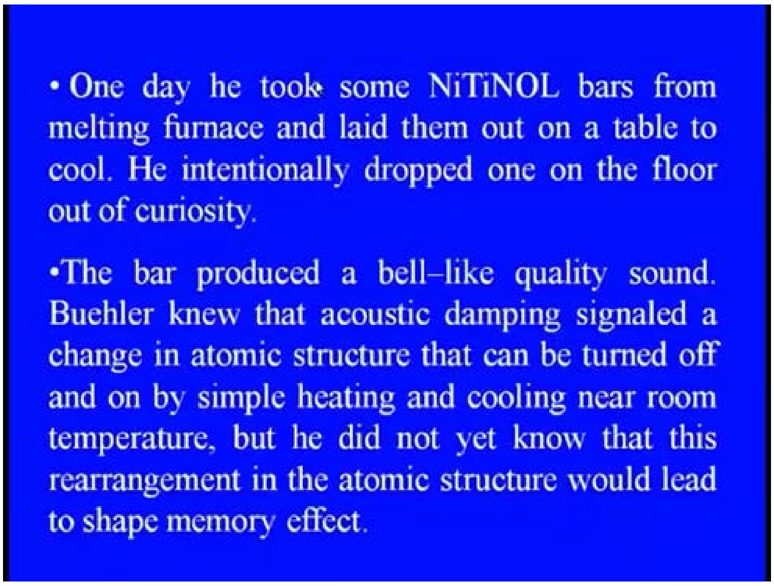

They observed this part especially their laboratory when they were working on these bars from the melting furnace, and then they laid down on a table to cool. And when you see you know like when he simply dropped this you know like, this we can say this part particular which is being you know like produced by this nickel and titanium part the alloy part, when if the small ball is being dropped down. Then he found that they were simply you know like creating the sound like the bell.

And you know like the Buehler knew that the acoustic damping signal is a clear change in the this atomic structure that can be turned off and on, by simply heating and cooling the near the room temperature. Because, you see here he knows that when he was doing this it was simply changing right from you see you know like these bell effect, to you know like the composite mixture of this nickel and titanium.

So, but you see at that time he did not discovered about you see that what exactly the changes are there at the atomic structure, which is leading towards the shape memory effect, when you see you know like when these heating or cooling's are been there along with the atomic structure. So, this is the you know like 1962 first time it was you know like discover that, there is a shape memory features are there, in the nickel and titanium based alloys.

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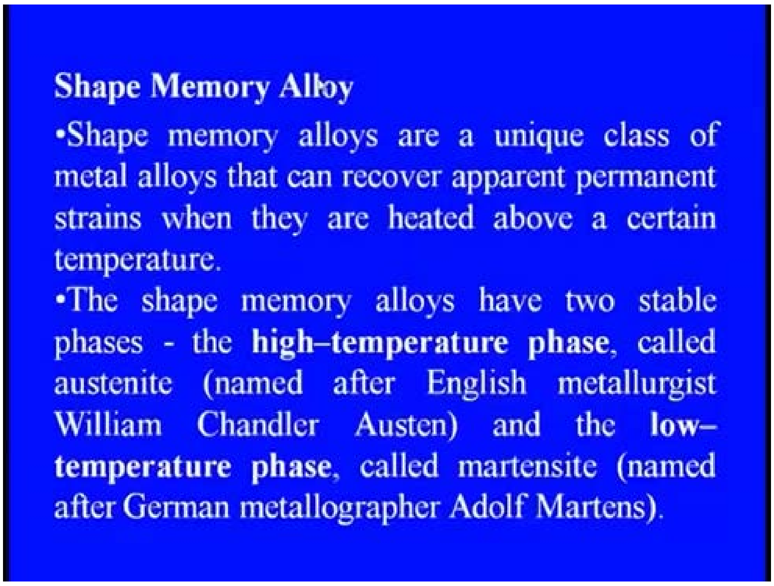

So, if you are talking about the shape memory alloy, these alloys are the unique class of the metal alloys that can recover the apparent permanent strain even when they are heated above a certain temperature. And these alloys have two stable phases in that, that is what you see at the atomic level, this entire microstructure features are the one when we are talking about the high temperature phase, which is also called the austenite phase.

Because, you see here this was mainly discovered by the english metallurgist called William chandler Austen. So, that is why it is the Austen this austenite phase is there, and second is the low temperature phase that is called the marten site, this is what you see basically a German metallorgrapher the Adolf martens. So, these see you know like Adolf martens or we can say the William Austen based on these two, you know like the discoveries.

Now, we have the two main phases, the austenite phase, the high temperature phase, the marten site phase that is the low temperature phase. And based on these you see here, we can simply exhibit the shape memory effects with the two stable we can say the phases with this.

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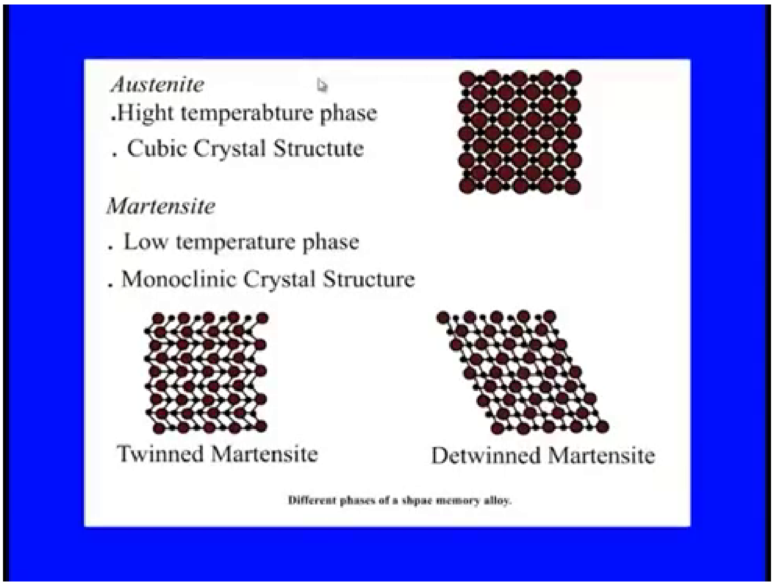

So, you can see on your screen that when we are talking about the austenite, which is the high temperature phase it is a clear cubic crystal structures are there, well arranged structures you see here. And you see whatever you know like the gaps in between the you know like these crystals are there that can be well arranged, the linear gaps are there. But, when you see the another phase when we are talking about that is the marten site the low temperature phase, it is what you see here the monoclinic crystal structures are there in which we have the two main part.

If you are talking about the twinned marten site, so this is what you see the twinned marten site, in which you see a clear twinning features are being appeared in the structure all along the molecular structure. The second in the monoclinic crystal structure at the low phase is the detwinned, the detwinned means you see here that some time you see here can see that there is perfect you see. They are not twinned to each other, it is what you see here you know like they are arranged in such a way that there is a clear difference is in between this, so it is the detwinned marten site phase.

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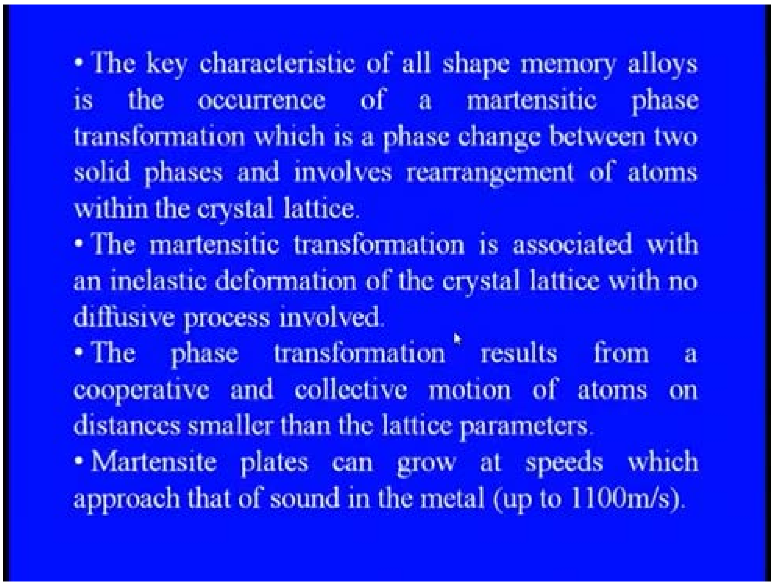

So, the key characteristic of all shape memory alloy is the occurrence of the marten site phase transformation, which is a phase change between the two solid phases and involves the rearrangement of atoms within the crystal lattice. So, this is the basic you know like we can say feature of the you know like the shape memory alloy, that when they are working with the low temperature phase that is the marten site phase transformation.

Then there is a clear change is there; that means, you see in this solid phase we have a clear involvement of the rearrangement of the atoms, within their crystal lattice all along the fibers. So, the marten site transformation is absolutely associated within inelastic deformation because now we have a plastic deformation here, so it is absolutely associated with the inelastic deformation of the crystal lattice with no diffusive process involved.

So, there is no diffusion is there along with the molecules, but this is what the plastic deformation is, and the phase transformation results from the you know like from a cooperative and the collective motion of the atoms, on the distances smaller than the lattice parameter. That is what you see one of the key part is that whatever the distances are there in between these molecules, during you see you know like we can say these recover part or the phase transformation, the distances must be lower than the lattice parameters.

And the marten site phases can grow at the speed almost you see approaches that to the sound of the metal; that means, you see when even it can be approaches up to the 1100 meter per second the sound speed. So, this is what the unique feature of these shape memory alloy, and in that you see the marten site phase transformation can be occurred in this particular process.

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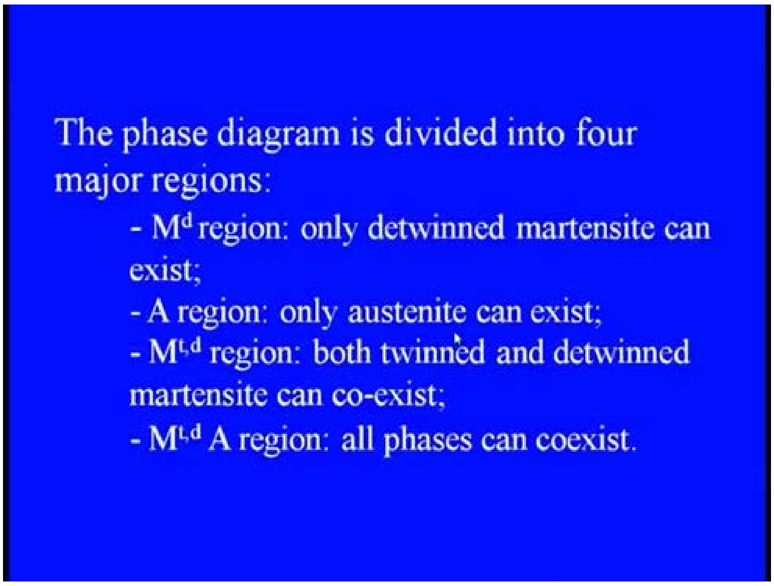

And the phase transformation the phase we can say diagram can be you know like shown in the four major regions we are going to show first the M d region. In which you see here the this detwinned this marten site phase is there, A region which is showing the austenite, the M t d region is showing both the twinned and detwinned marten site which can be coexisted together. And the lastly we are we are going to show the M t d A region in which all the phases can be coexisted.

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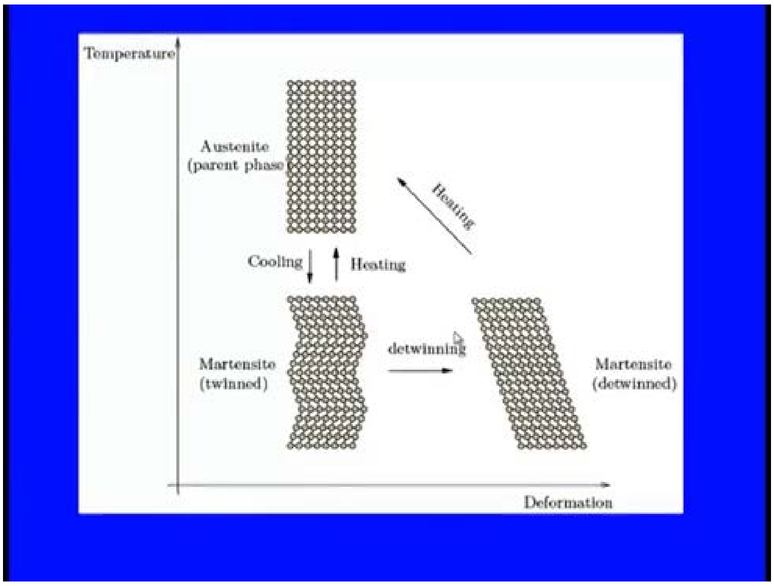

So, you can see that we have you see you know like the parent phase, which is the austenite phase in which you see we have a clear arrangement of these or entire you see the molecules. So, now, you see when we are you know like cooling to this part it is absolutely going into the, low temperature phase in this transformation the marten site transformation we have now the tuned one. You can see it is a perfect tuned one, just you see you know like the tuned feature is there, in which you see the you know like the molecules are being arranged according to the lattice structure.

And when we are doing the detwinning, then we have a clear feature of the marten site part, according to the deformation. And we have you see you know like all these we can say the arrangements are there, but there is no as such we have already discussed that, there is no collision features are there. But, they because of you know like the distances are much smaller than what their lattice parameters are according to the structure.

So, these are again you see you know like we have the detwinned now marten site phase, and these detwinned be marten site phase can be again go to you know like our austenite phase, while heating part. So, this is basically the cycle which shows the temperature and deformation features, when they are you know like heating or when they are cooling it is being you know like recovered in that part straightaway.

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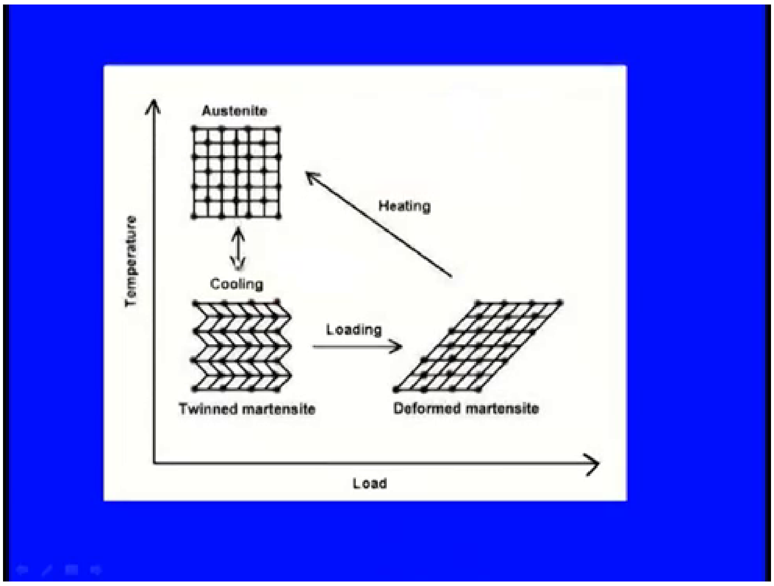

Rather you see we can show in that way also, that the austenite is just going into the twinned marten site to the detwinned marten site by loading part. And when the load you see this is the temperature load part, and when the after loading part you see when you know like the everything is well streamlined there then we can through heating we can go back to the austenite part.

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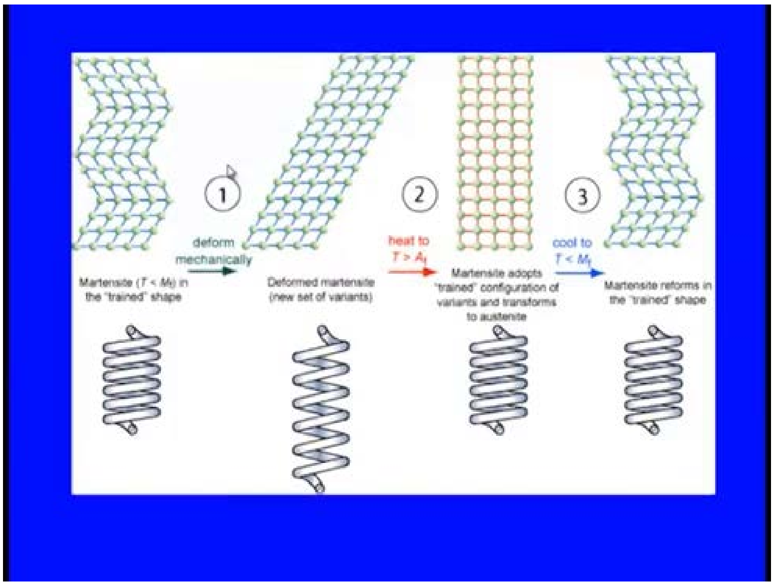

So, this is you see you know like one of the special feature which we can you know like put the analogue like the spring part. First part if we look at this, we have the marten site here, the marten site in which you see the you know like the T is less than the M of t in which you see you know like we have the trained shape, this is my you know like the we can say the twinned shape is there at the low temperature part. So, we have this is what you see the twinned parts.

Now, this is the first part when we are just trying to deform mechanically, so when the loading conditions are being there, then it is being detwinned marten site part in which we can say that the new types of you see the variants are there. So, when you are simply putting the mechanical loading, whatever the tuned feature is there, now it is detuned and the straight features which is clearly showing that, at the lattice structure how the molecules are being setup accordingly.

Then now you see here now we are applying the temperature, so if we are just applying the temperature the you see the marten site, which simply adopt the trained configuration of the variants is simply transformed into the austenite part. So, you can see on the diagram that you see, this reddish parts is clearly showing that here now with this detuned part, the heat is being added and it is being added to the connectors of the molecules, this whatever you see the bonds are there, within that the temperatures are being there.

And, now if the temperature you know like is being associated with this, you can see on the spring side, now it is again when the temperature is being given to that, it is being stored feature. And it is you know it is you know like the suppression is there the compression features are there, and then you see here now when it is being cooled down, again the austenite part the high temperature phase is being now transformed into the low temperature phase. The marten site we can say reforms to again same trained shape I am using the trained shape.

Because, the training is already is being given to the material itself, then you see according whatever the shape changes are there ultimately it is recovered it is old you know like the old shape according to the trained part. And then we have you see you know like this marten site feature means you see the low temperature phase with this tuned part. So, this is you see the original shape as you can see this, so this is what you see we can say the kind of mechanical transformation is there, right from the low temperature range to high temperature range.

And you see here in this, how the changes are being occurred at the you know like the microstructure level this is what it is. So, now, if you are just looking that since we are working in the inelastic region, and the recoveries are just like you see in the as per the elastic ward, as the temperatures are being changing.

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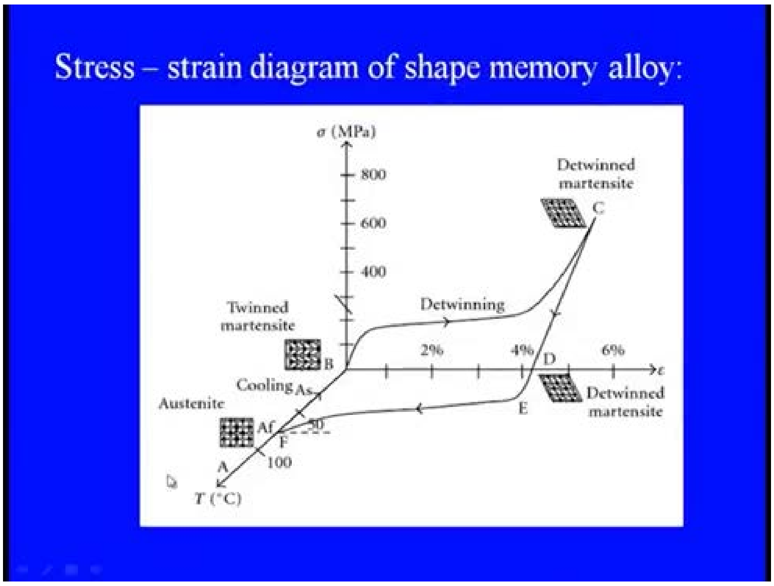

Now, we can see just you see now we are you know like in this stress and the strain part, and in this you see here we are absolutely at this point, where now we are just going to say at the marten site. So, this is my you know like the twinned marten site the first part, when we are cooling to this, then certainly we know that you know like absolutely we need to go towards you see you know like the low temperature phase, and by heating we can straightaway go to the austenite.

So, now here when we are at this you know like these austenite phase, which is absolutely at the 100 degree Celsius. When it is being cooled down to the 0 or you see you know like just cooled down to certain temperature, we have the twinned martin this marten site the low temperature phase. And when it is being detwinned means when the load applications are there, you can see that this is a clear non-linear deformation or we can say this is a clear non-linear behavior between the stress and strain, and it is a absolutely going up to you know like the detwinning marten site.

So, the C point, so when we are starting from A that is the austenite phase the high temperature phase by cooling down, we can be just transform into low temperature phase that is the marten site, twinned phase. And then you see after the load application, we can go to the detwinned marten site phase, means there is no temperature transformation, but there is a clear load applications are there. And this clearly makes the detwinning feature through which we can have a inelastic behavior in the alloy.

And after being you see here, when we are absolutely like just coming down means when the load application is being removed, they are just you know like coming back to this. So, up to even the detwinned marten site right from C to D, the load application is being removed, so it is a you know like we can say the reloading or unloading feature is there. And after that you see when we are just absolutely trying to do these part, when you see you know like the temperature is being reduced it is the temperature is being sorry the increased, it is absolutely you know like going. Because, it is at the low temperature phase it is going to high temperature phase, means up to the austenite. So, this is you see the stress strain temperature diagram, because you see temperature is also one of the important part in these shape memory part alloys.

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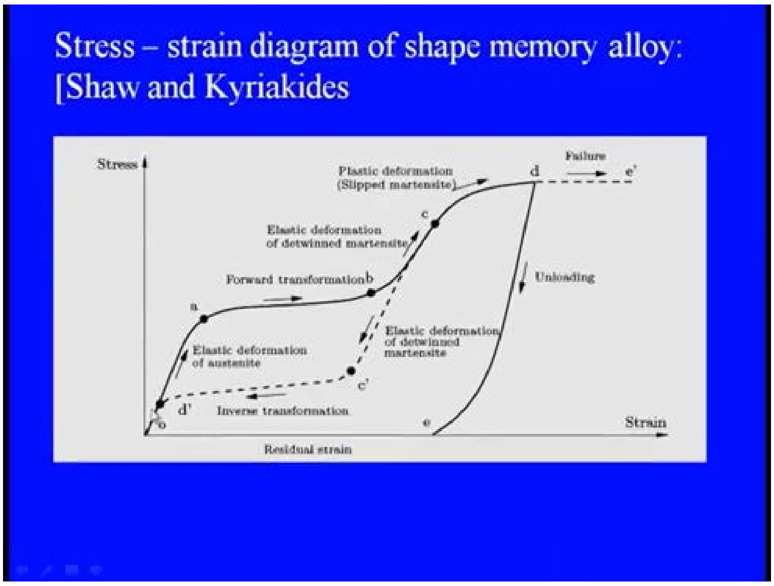

So, this is what you see you know like what we were discussing the elastic deformation austenite, and then it is being you know like when it is being loading condition. It is absolutely going to the failure part, when it is unloading part you see here, this is you know like the things are being coming. So, in the forward transformation or it is the you know like the inverse transformation, we have both the elastic or inelastic deformation feature, absolutely associated with the stress strain and the temperature part. So, this is you know like the graph which were experimentally shown by the Shaw and this kyriakides, in which you see it is a clear variations of the stress strain diagram.

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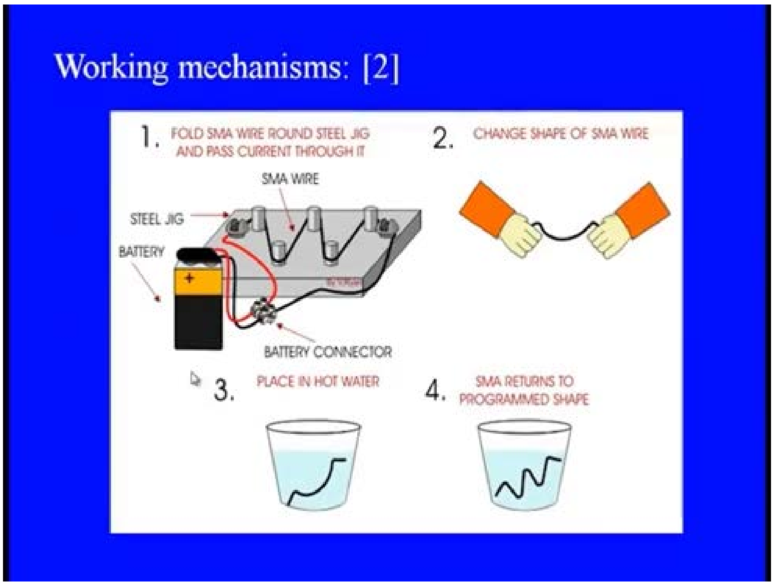

And if you are looking for the actual part, this is you know like one of the demonstration you know like showed in one of the paper. In which it is there that when you have you know like the fold SMA wire, which is being rounded there itself, you see you know like. So, what we have done here we are simply rounded this, and when we are just passing the current from that, it will take the straightaway shape that is what you see you know like the actual shapes.

When entire thing is being you know like this is what my conductor part is there, and the load through this battery is being applied there, it will take this shape, the zigzag shape. Now, you see this is what the original shape is there, when it is coming to say us example in the part two you can see that, with the stretching part now we just change in elastically the plastically we change the entire shape. So, you see here it the shape is now it is not zigzag, it is being changed now to the semicircular part.

And this semicircular part, if is now placed in somewhere high temperature region, say we are taking the hot water. When it is being taking putting to hot water, the low temperature phase will convert into the high temperature phase, means the marten site will be now convert into the austenite phase. And this austenite phase, which is being there you see you know like in that after some time, we will see that when the temperature is being raised up to that it will take the original shape of the zigzag.

So, this is what you see the initial to final the shape recoveries are there, and this shape recovery is absolutely under the plastic region only. So, you can see that this is one of the you know like we can say, this excellent property which thrills us that how you know like the things are being happening, when only you know like the temperature changes are there. And because of that even the plastic nature of the alloys are being recovered even at the loading and unloading conditions.

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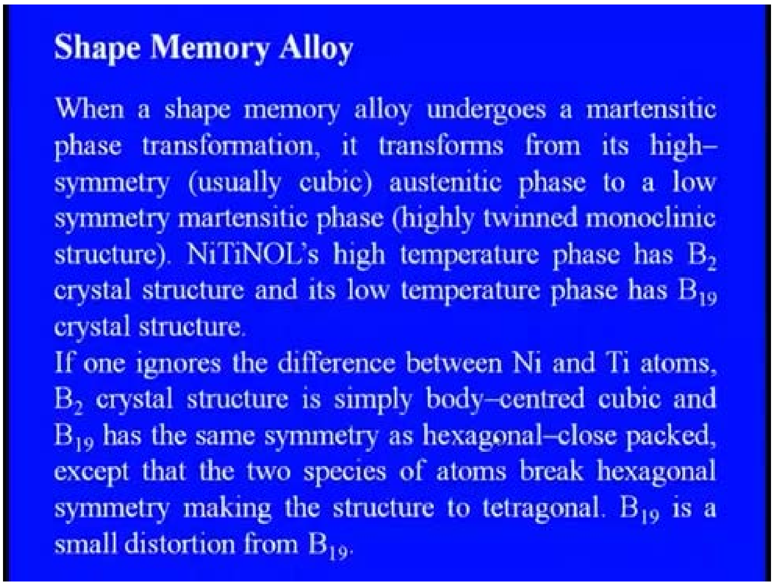

So, when the shape memory alloys undergoes a marten site phase transformation that is what we discussed, it is always you see you know like transformed from the high symmetric. Usually we can say the cubic austenite phase to low symmetric marten site phase, which is highly we can say twinned moloclinic structure, which I shown there. So, even if you are talking about the nickel titanium based alloy, the high temperature phase which has you see you know like the B 2 type crystal structure, and the low temperature phase they have been you know like this B 19 crystal structure.

So, if we are just see if you are just looking towards the these nickel and titanium atoms, we can simply see that the B 2 crystal structure, which is associated with the thigh temperature phase, they the simple body centered means B c c type of structure. While B 19 which is associated with the, the marten site phase the low temperature phase, they have the HCP type of structure, the hexagonal closed packed structure.

So, you see here when we are just changing from a high temperature to low temperature the B c c structure, which is associated with the nickel titanium is absolutely converted into the HCP type of structure with the we can say marten site part.

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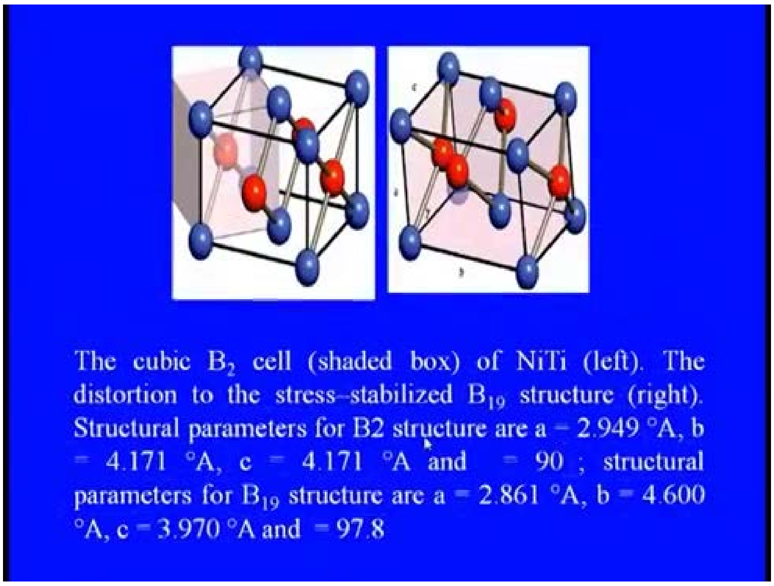

So, this is what it is you see here, we have you see you know like the cubic B 2 you know like the we can say in the shaded box it is clearly there, that we have the B 2 type of structure. In which the nickel titanium parts are being there, and when the distortion to the stress is being stabilized the B 19 structure this one, you can see it is clear reorientation parts are there in the low temperature part. Where you see the permanent deformation are being happened, and the structural parameter you know like which we can you know like taken.

Because, it should be lower than whatever the lattice parameters are there, they can be straightaway configured according to the nickel titanium alloy. And this was basically shown you see, you know like in this N i T O L that you see these are the specified this in this particular naval laboratory, with the based on nickel titanium that these are the basic properties and the parameters which can be taken with the nickel titanium alloys.

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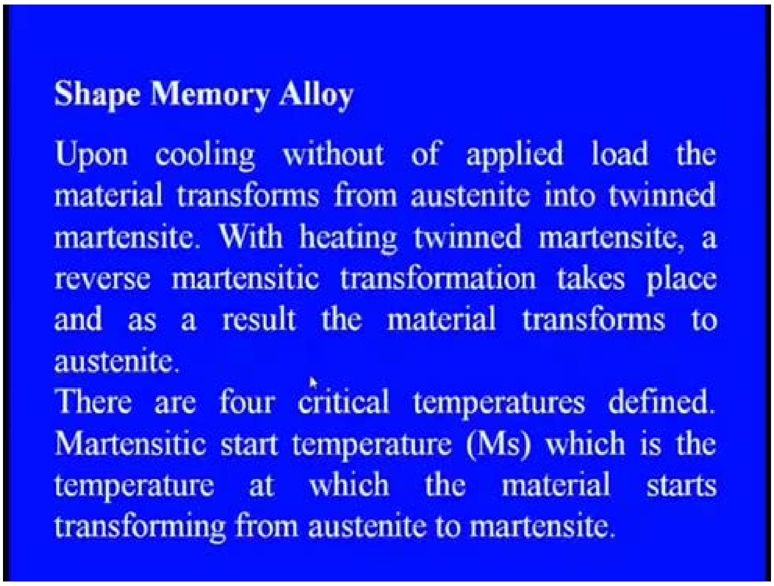

So, upon the cooling without applying any load, the material is transforming from the austenite to the twinned marten site. And with the heating of these twinned marten site, reverse you know like we can say the marten site transformation takes place and because of that you see here we can even reach, means the material transformations are there and that can be reached to austenite. So, this is a perfect cycle is there in the plastic region, and there is no load applications are there in that.

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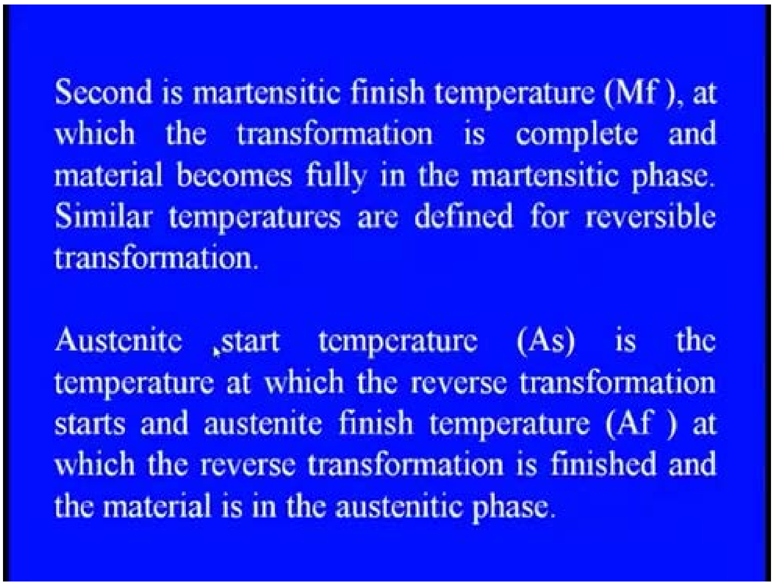

So, there are four critical temperatures which can be defined there, the marten site start temperature, which is nothing but the temperature at which the material start transforming from austenite to marten site, because you see here now the critical temperature is there basically which is being now cooling down, from austenite to the we can say the marten site.

Second is the marten site finishing temperature M f, again you see in this the two things are there one is the M s it nothing, but the marten site start temperature. Second is the marten site finish temperature, at which the transformation is absolutely completed, and the material becomes fully marten site the low temperature phase. Because, now there is a absolute cooling is happened, and similar temperature are being defined as the reversible transformation. Means the austenite start temperature which is nothing, but the temperature at which the reverse transformation starts and austenite finish temperature is the reverse transformation is finished, and material is now remained in the austenite phase.

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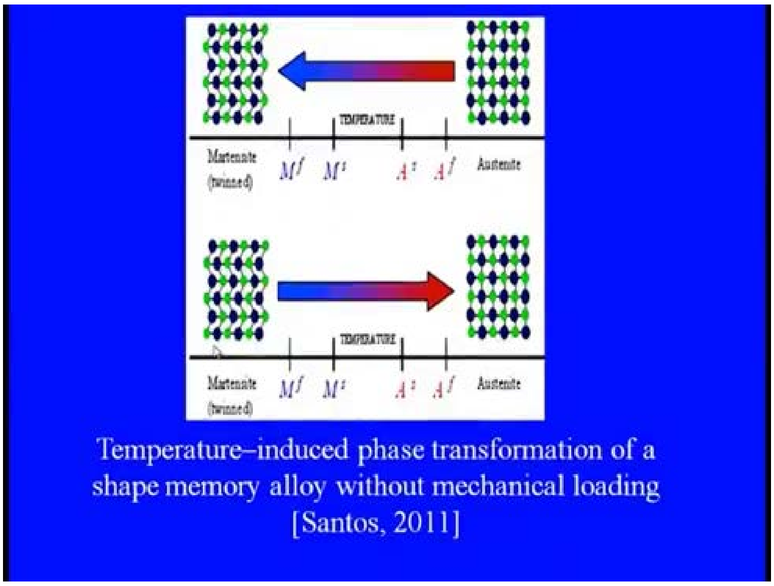

So, based on that you see now we can see that transformation as we discussed, it is what the marten site twinned form, now we have M f, M c this A s and A f. So, you see here when these transformations are there from austenite to marten site, you see there is a clear transformation from A f to M f, while when we are just going in the transfer phase where you see the temperatures are being increasing from marten site to austenite.

Then you see that this from the this twinned marten site to, austenite part it is starting from M f means the start this marten site phase and ending up to the this finishing of this austenite phase. So, this is what you see the total cycle is there, when we are just heating or cooling the entire features.

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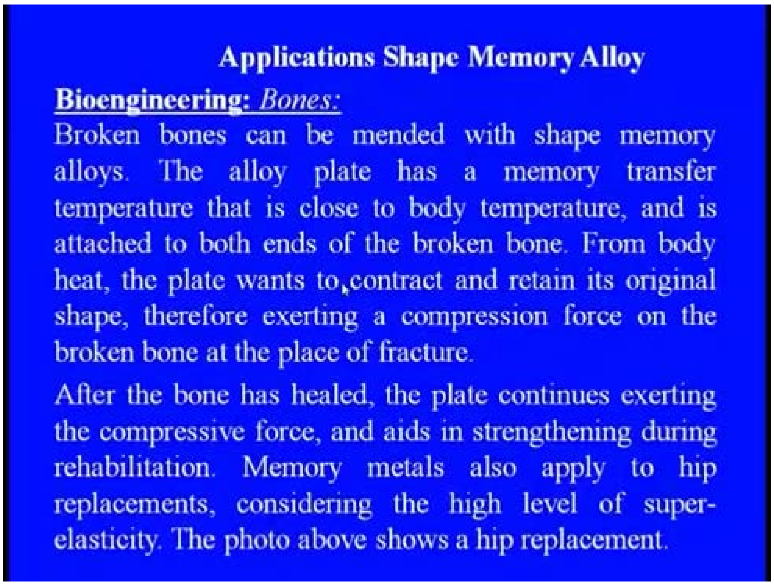

Now, there are lots of applications of the shape memory as we discussed that the broken bones can be mended with the shape memory alloys. And the alloy plate which has you see the memory transfer temperature that is very close to the body temperature only, and that can be attached to the ends of the broken bones straightaway. And when the body heat, the plate wants to contract and retain it is original shape.

Therefore, you see you know like exerting a compression forced on the broken bone, at the place of the fracture these you know like things can be easily happened, and it can be appropriately put together. So, after the bone has been healed you know like when we are saying that you know like everything which is being processed, and the healing is being completed. The plate continues to exerting the compressive force and add the straighten the straightening means the strength part during the rehabilitation.

So, memories metal also applied to hip replacement with the consideration that high level of super elasticity feature should be added there. Because, now this is what you see the various you know like the circulatory motion is there, in the all direction means you see here this is what you see, you know like the rotation features are there at the joints. So, we can say that it is a clear the hip replacement is can be done with the using of these shape memory alloys.

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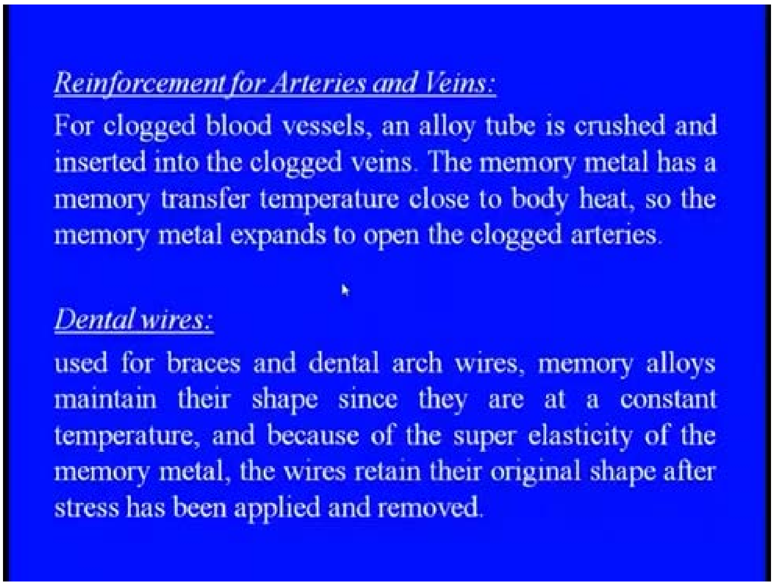

Second is the reinforcement for arteries and the veins, so in biomedical science you see now this SMA can be use straightaway. So, for clogging blood vessels and alloy tube is crushed and inserted into the clogged veins, and the memory metal has the memory transfer temperature which is close to the body temperature or the body heat we can say. So, the memory metal can expand to open the clogged arteries, so you see here there is a clear interaction between the arteries and the veins, at the clogged blood vessels and you see here we can be straightaway featured out as per the body temperature.

And corresponding you know like the required actions can be automatically happened with the heat variation, and as I told you that it can be also used as the dental wires. So, you see here the SMA you know like where they are using as the wire, they can be used for the braces or the dental arch wires. And these you know like the SMA alloys, can maintain their shape since they are at the constant temperature.

And also because of the super elasticity of the memory metal, the wires retain their original shape even after the stress. Means we can straightaway applied the stress, and it is going up to the plastic nature or if we removed the forces and it can be comeback it is original shape.

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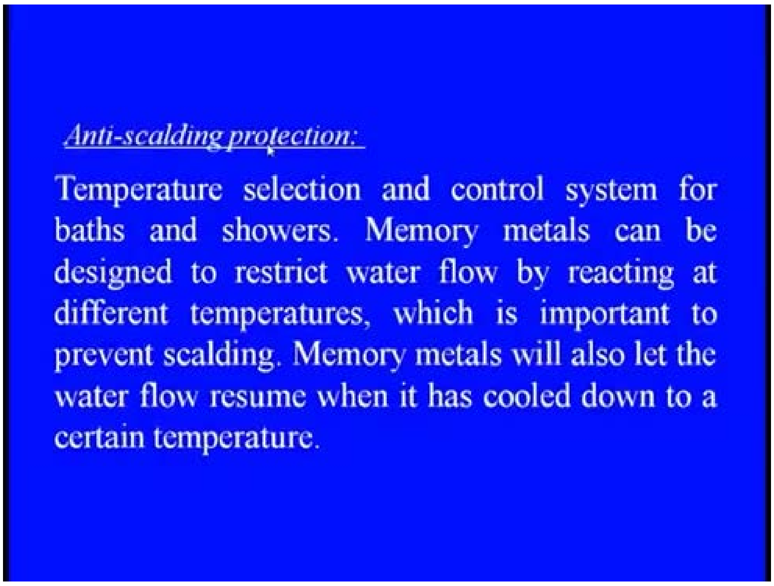

Even it can be go up to the anti scalding protection where the temperature selection in the control system are you see the baths and the shower. These memory metals can be designed to restrict the water flow, by reacting at the different temperatures and that is why you see we can prevent the scalding effect. So, memory metals this SMA metals will also let the water flow resume, when it is being cooled down to the certain temperature. So, on off features can be straightaway happen according to the water flow, controls are being required there. Even that can be used for the fire security and the protection systems.

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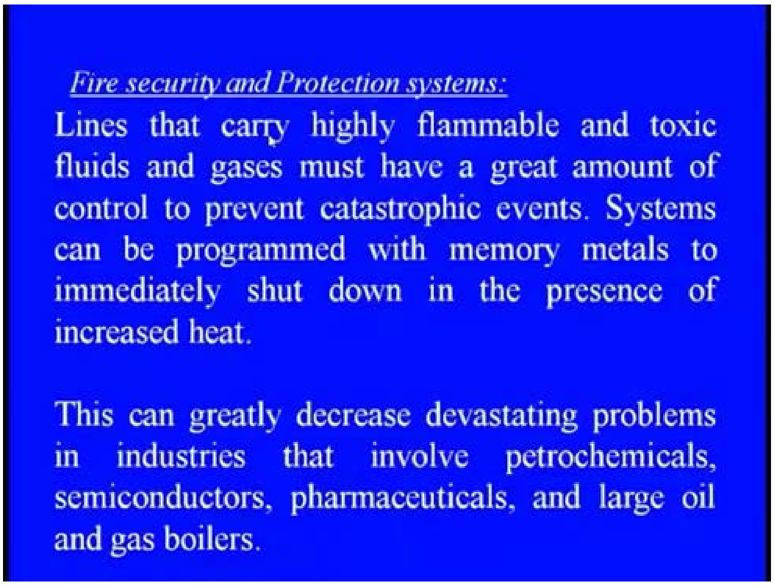

So, you see here when we know that the lines which are carrying the high flammable or the toxic fluids or even these you know like the highly sensitive gases, we need to you know like take care up to the greater amount of these control to prevent the catastrophic events. So, you see here you know like we can use straightaway, the shape memory metals to immediately shut down the presence of the increased heat. And this can be greatly decreased, by you know like devastating problem in the industry which involves a petrochemicals, semiconductors, pharmaceuticals or even you see you know like oil or gas boilers. Where you see the temperature sensitivity features can be added, and you see in the effective control features can be put by these alloys.

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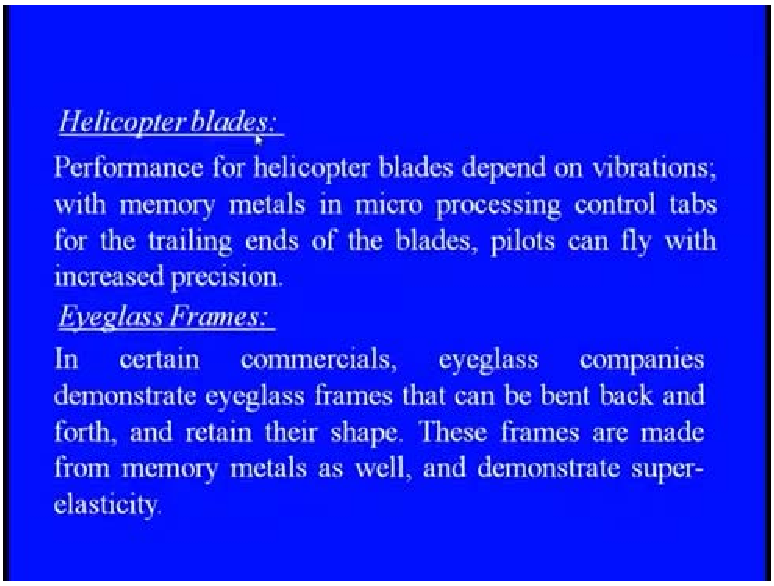

Helicopter blades even you see you know like the eyeglass frames, they can also be in these also these SMA have a clear application. When we just want the helicopter blades should be perform you know like and you see here, you know like accurate way and the vibrations are being you know like very common. So, memory alloys memory metals or memory alloys in the micro processing control tabs, can be trained can be put you know like at the trailing end of the blade.

And you see here when the highest precession is required during the operations, they can be straightaway you know like put just like the dampers. And at the time you see here they can be also retract those actuation part or even when you are talking about the eyeglass frames. Now days you see you know like just like when it can be bend back or the forth or even retain their shape, these SMA alloys can be you know like use there.

So, these frames are made from the memory metals, and they can demonstrate with the super elasticity feature all these you see you know like the, we can say the bend back or the forth or like the reverse part can be straightaway happen with this.

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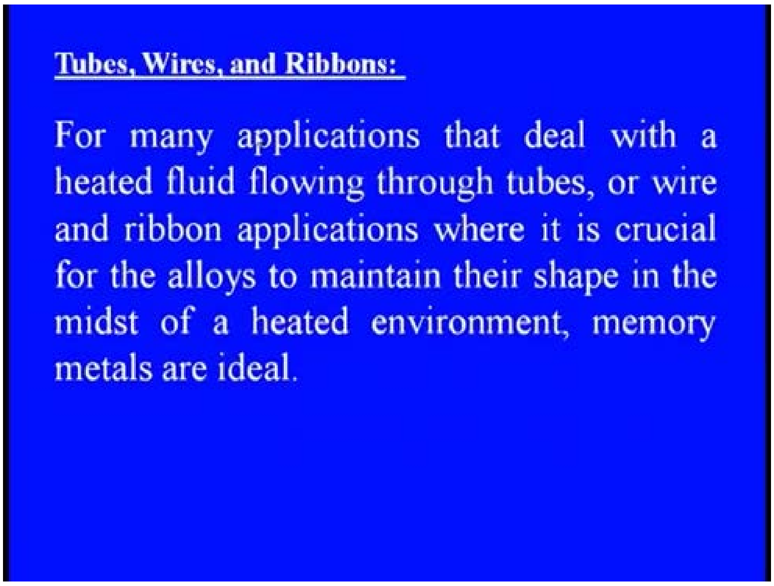

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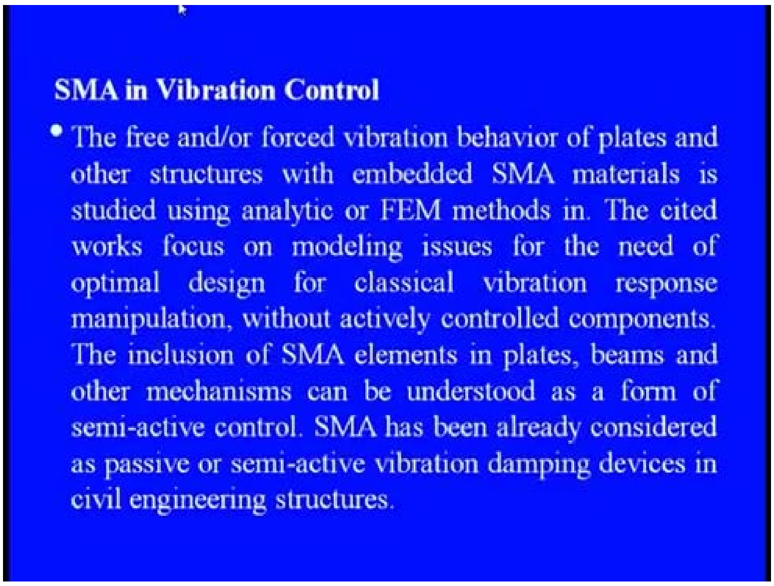

Even for the tube wires and the ribbons especially you know like wherever the requirements are there, these alloys can be straightaway you know like adopted, there itself. And they can maintain their shape and you see the midst of the heated environment these alloys are absolutely with this.

And now when we are applying these two the vibration control we can straightaway use that, this free or the forced vibration behavior. Where we just want to see these things, we are just taking the plates or any structure, in which we can simply embedded the shape memory alloy material in that, and then we can simply see in that what exactly can be happened. So, there are various cited works are there on that in which you see the modeling can be modeling's are being done or the experimentation have been done with these.

So, you see here we can see that what exactly the optimum location, and the optimum designs are there for a perfect vibration suppression. Because, you see here we can immediately see that, when the actuations are being there and we know that you see we just want to you know like just you know like suppress the vibration we need to see that what exactly the molecular interactions are there, and what the temperatures are being forming there itself.

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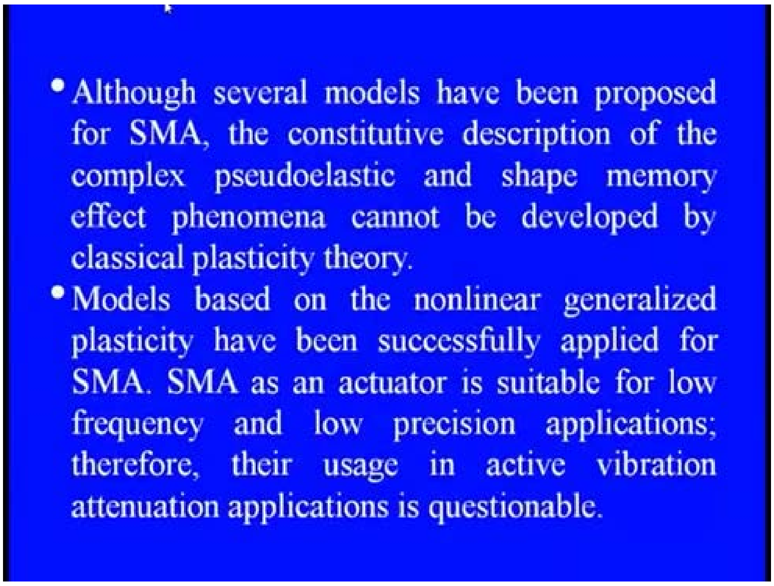

So, the inclusion of this SMA elements in the plate beams or any other mechanism, can be understood as a form of a we can say semi active controller. Because, we know that you see here you know like if we are even taking any civil structure also that can also be embedded in those. And there you see here whatever you know like the during the loading and unloading part, they can be clearly exhibit these you know like the entire this cyclic features there itself in the control.

So, now you see here we just want to see that how the things are being really working in this. So, you know like when we are talking about this the shape memory alloy model based, the non-linearity is clear you see you know like feature because we are just talking about the plasticity feature. So, when we are talking about a generalize plasticity we know that the SMA is a perfect part, so SMA as a actuator is quite suitable for the low frequency, and low precision applications. There you see we can say that, even for active vibration this attenuation application is a real main part, means main you know like we can say the questionable features are there in this.

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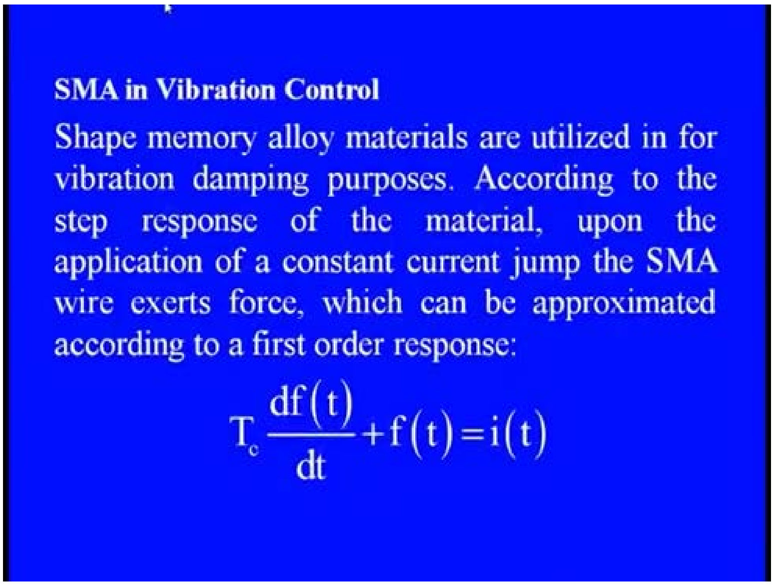

So, the shape memory alloy material can be utilized in the vibration damping purpose, and according to the step response of the material upon application of even the constant current jump or anything is there. The SMA wire which is being you know like exerted force, which can be approximated according to the first order response is whatever the critical temperature, and the applied force say the excitation force is there. So, what is the rate of change of that forces, so T into d f t by d t plus these the excitation forces are there can be you know like make it equals to the current jump is there at the SMA wire.

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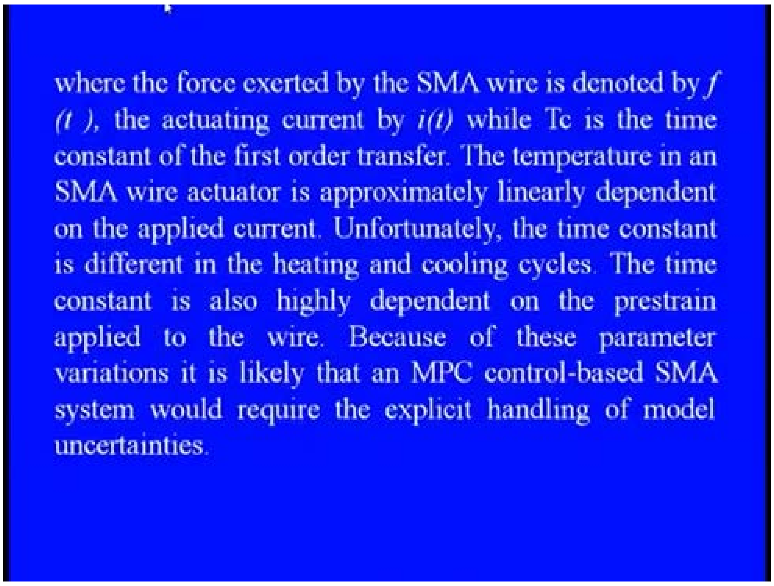

So, whatever the force which is being exerted, the actuation current is being there by the i of t. And then you see when we are saying that the time constant is being there which is simply showing the linear variation of the first order, we can make the equation which is well balanced equation. And the temperature of this SMA wire actuator is approximately linearly dependent on the applied current itself. And because of these parameter variation we can say that, we need to use the MPC controlled based SMA system to you know like handle the entire system at you know like perfect level without any uncertainty.

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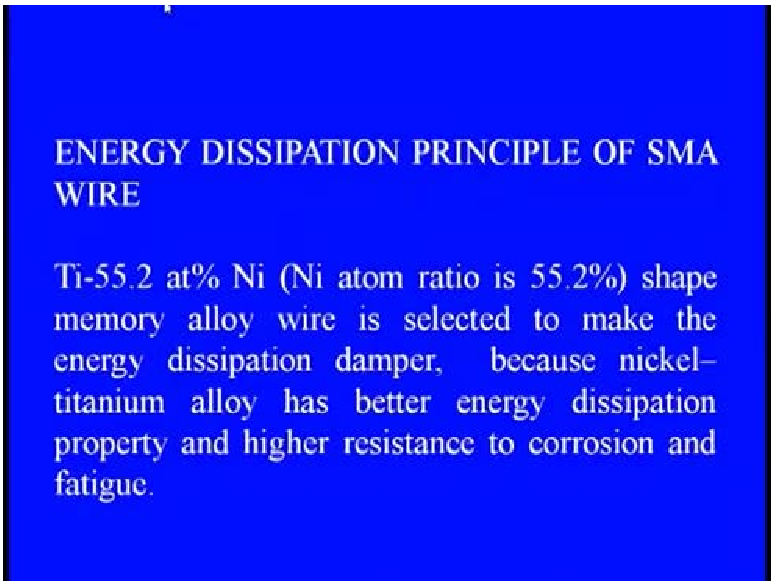

So, now if we want to see the energy dissipation because you see they are working as the damper feature. Then we can say, the titanium this T i 55.2 at we can say whatever the percentage of the nickel is means it is nothing, but the 55.2 percent of the nickel atom ratio. The shape memory alloy wire is mainly using for the damper in which you see here, the energy dissipation features can be effectively done, and because the nickel titanium alloy has a better energy dissipation property, and the high resistance to corrosion. And the fatigue they are the perfect we can say, these elements for the damping feature.

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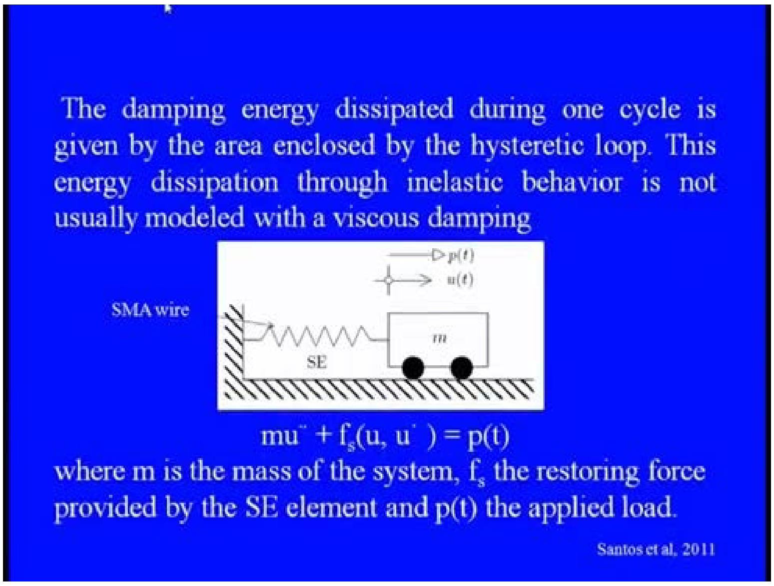

We are taking now this you know like the example for the single degree of freedom system, in which the damping energy. Again remember this energy is being dissipated during one cycle, in that you see here you know like we know that when it is being entire cycle is been completed the loss of energy is also being there as the hysteretic loop. And this energy dissipation through the inelastic behavior because we know that this is the permanent set of this part is there.

So, this whatever the energy dissipation and the absorption during this inelastic behavior is not usually modeled with the viscous damping feature. So, we have you see you know like you can see that, we have the spring this spring is not the metallic spring this spring is basically from the SMA wire. So, this is the spring energy is there, and these mass which is being varied with this part, so we can now put the equation of motion, as we have already discussed m u double dot plus f times of you see this is what my you know like the displacement.

So, m x double dot we can say or m u double dot plus f s u and u dot, so this is now you see you know like it is absolutely focused on u and u dot both and p of t. Where m is the mass and f s is the restoring force provided by this SE element in which you see, the SMA wire is there. And which is you see you know like linearly depending on not only the displacement, but also its derivative velocity, and p of t is my applied force as you can see on top of that.

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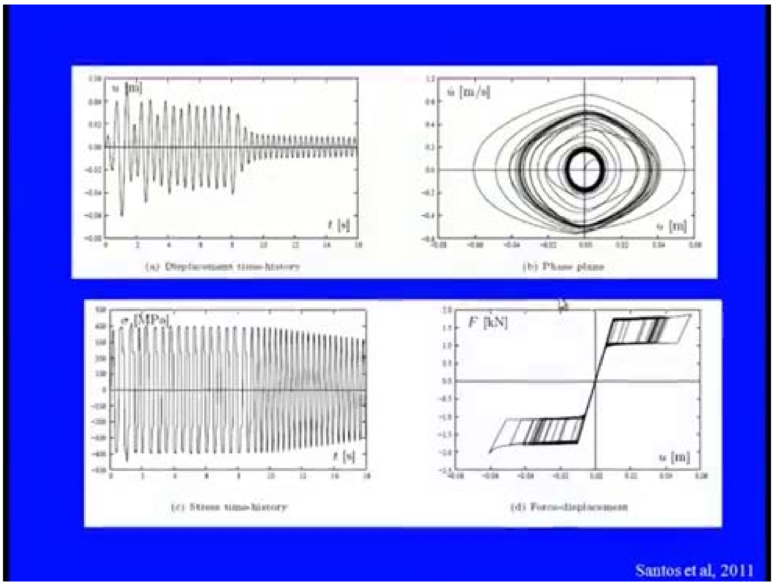

So, when we are now you know like the single degree of freedom system is and that is the equation, now you see the responses which was basically you know like presented by this Santos et al in 2011 paper. That you see when these you know like the SMA wires are being added, they are the effective tools for the suspension or we can say the this dissipation of energy, then they are acted as the viscous part. So, you can see that the time displacement response up to this part you see the amplitude of the variation in the displacement feature is a great amount, and when this SMA is acting here.

You see there is a period you know like the absorption feature, and the smooth run is there. Even here you see when you can see the phase plane, the phase plane diagram between the you know like we can say this with the displacement and velocity, this inner energy is, so huge you see here. And when you see you know like the SMA is being acting there see the entire displacement part, the entire displacement you can see on outer part is being absorbed, and it can be straightaway focused on the inner circle part.

Even we can say the stress time history, you see the initially stress this part is quite significant, the stress is the amount of the stress is, so high all across the material feature. And when you see the SMA is being applied there, this is you see the clear stresses are becomes now the linear feature. And when we are going with the forced displacement, you can see that this is what the non-linear behavior, when it is being transforming in the loading and unloading condition. And then you see this is what you see the entire cycle features are there.

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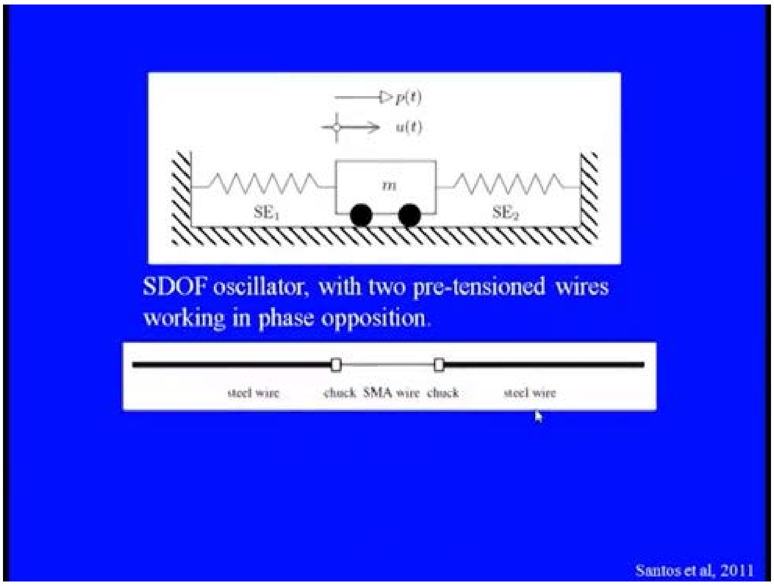

Even when we are going to the other part, when you see you know like the single degree of freedom oscillator is being you know like there in between the two pre-tensioned wires. And both the wires are having the shape memory alloyed feature in that, so how they are making you can see this is what the demonstrations are that we have you see you know like the steel wire, on both the side and in between we have you know like chuck of the SMA wire. So, these two chucks are being just carried our shape memory alloy wire and outside you see this.

So, when these you see you know like the SMA damper when they are being working together, along with the spring and the damping feature. Now, we can get you see the equation of motion for this and we can see the responses, so here we have a clear this restoring forces interaction with this mass m to SE 1 and SE 2 as well. And we can make the force valance and we can get the responses.

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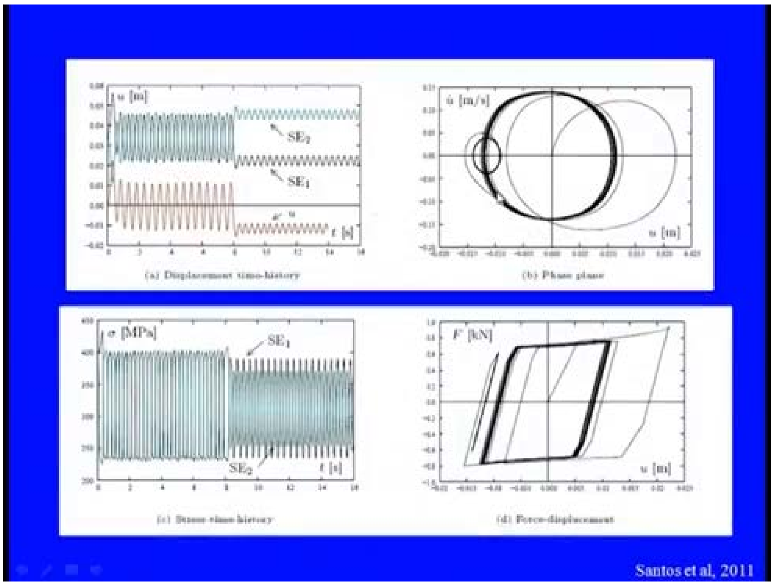

So, the responses if we see here then we will find that, this is what you see you know like the initial displacement time history. It is a very a unique feature, it has you see the highest you know like we can say the displacement, and when these SE 1 and SE 2 are working, you can see with the SE 1 what a great reduction of these you know like the displacements are there and with this.

And even when we are just working with the other part, you see this in which the time histories are there, you can say this is a clear change here. It is a clear change of the time histories are there, when the things are being happened like this. So, when they are you know like we can say tuned or detuned feature, these you know like the controlling effects of this is pretty obvious. Second when we are talking about the phase plane, it is a kind of quasi static feature, when you see you have the two different loop.

But, these loops are straightaway controlled and it can be controlled up to that level, even when we are talking about you see you know like the stress time history part. The stresses are being featured out and we have you see SE 1 and SE 2 in this way, and when we are talking about the force displacement feature, this is what the cycle the load and unloading cycle are being formed according to the plastic flow, and it the hysteresis loop can be framed in this way.

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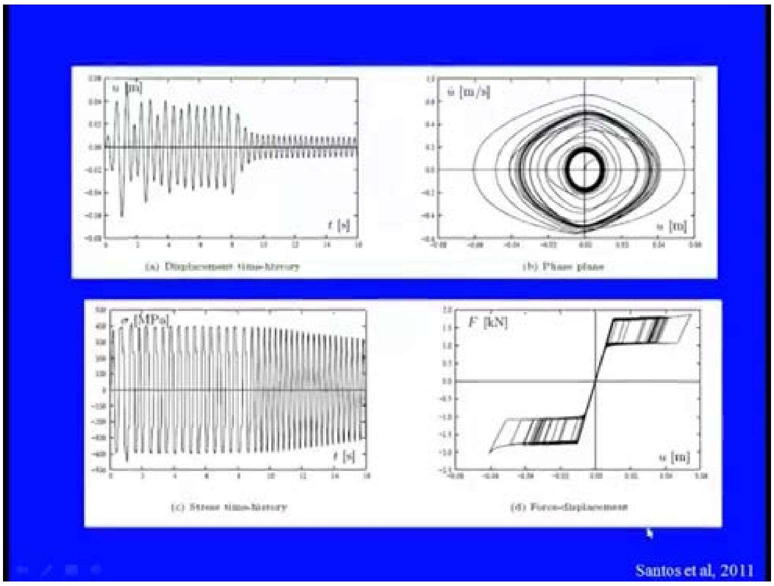

So, when we are talking about the single spring this is what my hysteresis loop and these you know like the formations of the load this force load transfer this variation is there. And when we have the two springs you see here, the SE 1 and SE 2 both are working in such a way that, we can get you see these transformation with the you know like the marten site to austenite, and you see these all variations are there.

So, this is all about you see the shape memory alloy in which you see, we discussed about some fascinating property of the material. When you see here, they are just having some kind of you see anthropomorphic features that they can memorize the things, whatever the changes are there in their shape, after you know like the loading or when the during the recovery features. They can be rephrased or reframed them into their original shape.

And then you see here with their own material property, and the micro structure formation, they can be straightaway act as the actuator feature or they can be straightaway act as we can see here, by you know like these centers experiments. That you see you know like there is a clear damping feature is being provided along with the spring and the damping you see here, that clear vibration dissipations are there with the stories of the energy.

And then the stable formation in the phase plane you can see that, they are simply showing the stable formation of the entire vibration part. And this is the beauty of you see the shape memory alloy, when they are working you know like under the even we can say the high temperature or high force excitation, they can be straightaway act you know like against that, and we can get the effective control of the vibration with the using of the shape memory alloy.

Even they are being based on the nickel titanium or any other thing we need to check it out that what exactly the base metal, and what you see you know like the requirement of the force or the exciting frequencies are there. Through which we can use a different type of materials, and still the research is being going on that how the micro structure is being changing, when the marten site or austenite phases are being there, and what kind of material or the alloys can be framed. So, that we can get an effective damping feature, from these you know like the shape memory alloys.

So, this is all about this chapter and then you see in the next chapter, we are going to discuss about the again you know like one of the important material, which we are saying that you see how the dissipations are being there from the you know like the various material properties are there. And also we are trying to solve some of the numerical problems, for the vibration control when you know like which we discussed that, when the mass is being tuned to outside.

The tuning masses are there or added masses are there or even when we are trying to put some kind of isolator or absorber, then how you see the you know like these examples are quite real examples, you know like with that you see here you know like how we can effectively control the vibrations for the you know like the machines, which are being there in our house or in our you know like the industries.

Thank you.