Advanced Materials and Processes

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Lecture - 21
Advanced AI Alloys Part – IV and Ti Alloys

In last class, we were talking about titanium based alloys. And we will get and the various types of titanium based alloys alpha, beta, alpha plus beta. And we will plate by the philosophy behind mix alloys, which alloy should be used for what kind of applications, why alpha works better for high temperature strength, when compare to beta. And what are the advantage of the beta? As far as formability is concerned, when compared to alpha we look at all of them.

Today, let us try to look at another aspect of the alpha, beta alloys. And then go to the other type of titanium based alloys which are the ((Refer Time: 01:32)) alloys. So, when we talk about the mechanical properties of alloys particularly. We come across three types of properties, the strength, the ductility and the toughness.

And for most of the common I would say consciousness people usually considered ductility and toughness to be almost synonymous to each other. But, we know that they are not like that, it is possible that material can be highly ductile. But, at the same time not tough and at the same time material can be highly tough. But, at the same time not ductile, because the two are though they are relate to some kind of deformability.

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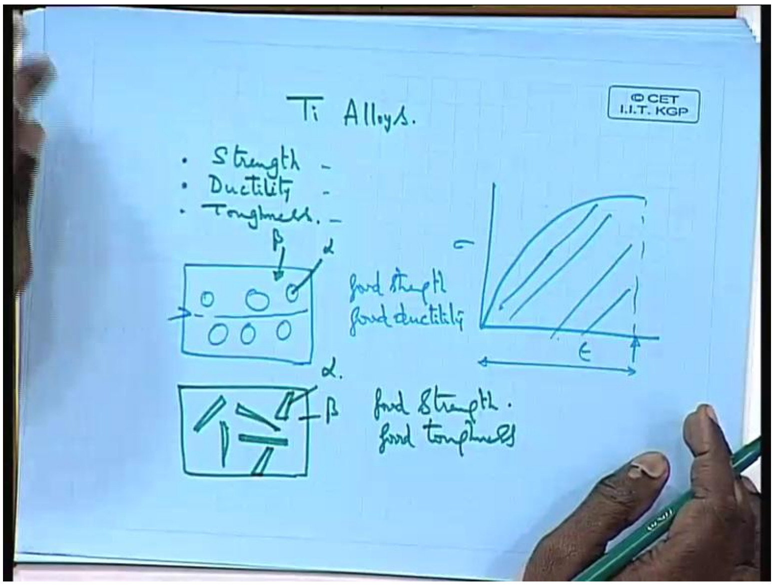

But, there concept are entirely different. The ductility is basically is the amount of deformation, that you can give into a material before it fails. That is what is ductility, percentage elongation we talk about and percentage reduction in area. So, that is ductility. That means, how much of deformation you can, how easily a material can be deforms, that is a measure of the ductility.

But, when you talk toughness, toughness is basically the resistance of a material for the track propagation. Whenever, you have a crack initiated in a material. And if the crack propagation is made more difficult, then we say the material is more tough. In fact, quantitatively measuring, we take the area under the stress strain diagram.

If you have the stress strain diagram like this the stress and the strain. This area under this stress strain diagram is nothing but the toughness is not it, that is how we measure. And percentage elongation is the total elongation, that you have before the fracture has occurred. So, that is the percentage elongation.

So, this is as far as quantitative is concerned. But, qualitatively we know that the two concepts are different, one is about deformability, another is about the resistance of a material for the crack propagation. So, that is we say brittle material has very poor toughness. Because, a cracking very fast it can propagate in the material; and then finally, the material will break.

Whereas, a material for example, if you take a Marten site, Marten site you say is very tough, under many conditions. In many alloys Marten site is very tough, though it may not be very ductile. So, what is this, what controls this, how to control the microstructure to control these two properties. That the ductility and the softness; and finally, the strength also.

And to ultimately get a proper combination of or an optimum combination of all these three; this is one effort which in titanium base alloys, people have successfully achieved. And that is trend to control the microstructure of all those things. We know that alpha is a low temperature microstructure, low temperature phase. And beta is a high temperature phase.

So, if you take a high temperature beta and try to cool it what you get's from that. When, you take a beta which is at high temperature. And start cooling this beta, alpha should precipitate out of it is not it. So, depending on the composition, the volume fraction of the alpha is going to be different.

So, usually alpha has to unless, you are talking of those alloys, where a large amount of beta stabilizers have been added. In such a weather beta gets stabilized even at room temperature. So, if you do not consider such type of alloys. All those alloys where you have a alpha plus beta possible at room temperature. When, you take it to high temperature it is beta and when you start cooling it gives alpha.

But, now the question is depending on the morphology of this alpha, inside the beta the properties are going to different. If you have a microstructure of beta, in which you have alpha as this kind of spherical particles let us say. Or you know some kind of more or less particles. In this kind of a material if you look at the mechanical properties, you will have a good strength.

Because, it is the mixture whenever you have two phase mixture, you get good strength this is known to us. And then if you look at the ductility aspect of it, this metrical will have very good ductility. It will have good strength, good ductility. Why good ductility, because the particles are spherical. And because the particles are spherical, the material can be easily deformed.

There is no tri axial state of stress coming into picture, this is what we have seen in case of even spheroidal graphitoidal iron. Or when we take high carbon steels, the high protectors steels and ((Refer Time: 06:50)) is the cementite, there also we see that we can improve the ductility is it not? So, because whenever you have spherical particles.

So, you will not have a tri axial state of stress at the corners. The particles, if the particles present in the material are needle shape or a secular. That is, when you will see at the tip of each of this particle, you will have a stress concentration taking place. And that is what is going to lead for the crack initiation, and finally the fracture of the material.

So, you have to avoid stress concentrations. And the best way to avoid stress concentrations in a two phase material is to have spherical particles is not it. So, that is why this material gives you a good ductility. But, it will not give you a good toughness. Basically, because if a crack is initiated inside the material, let us imagine a crack is initiated here, it can easily propagate.

Because, these are all mostly spherical particles, spherical particles do not really offer much resistance for the crack propagation. But, if you have a secular type of particles, particularly which are randomly oriented. That means, if you have a microstructure, let us look at another type of microstructure, where you have this type of secular particles in a beta matrix.

The matrix is beta and these particles are alpha, again here also is the same the particles are alpha and the matrix is beta. If you look at this kind of microstructure, this microstructure will have like the first microstructure, it will have good strength no doubt. And it will have good toughness ((Refer Time: 09:04)) and but it will have poor ductility.

The ductility of this alloy will be very poor. So, as a result we can see, that these two type different microstructures, one is having a good ductility, another is having good toughness. And the few do not have for example, the first microstructure do not have a good toughness. And the second microstructure will not have a good ductility.

So, this is something which people know quite before. And in titanium base alloys, they tried to see how we can achieve a combination of these two. The easy way to say is, try to have both type of the particles. The question is how to have it. So, what people tried to do is, we know that the morphology of the second phase depends on the way, we do the heat treatment.

And particularly depends on the temperature at which the precipitate comes out. Usually, if you have a high temperature single phase, such has a beta. And if it is cooled very fast to a low temperature. And if the precipitation starts at a low temperature, at low temperature the precipitation usually is a Wigwam Staten type a secular type of precipitation take place. The reason is, at low temperature the precipitates, because the diffusivity is very low. The precipitates that come out will be those, which can be coherent with the matter. So, usually a secular type, disk type or plate type or needle type precipitates will come, which can have some coherency or at least a semi coherent interfaces with the matrix. This usually occurs at much low temperature.

So, as a result if you can have the precipitation occurring at much low temperatures, we are assured to get this kind of a secular precipitates, and if the precipitation occurs at temperatures closer to the transformation temperature. If the delta t is very small, if the delta t is very small, the precipitation usually is by more or less spherical type of precipitates, which are called grain boundary alert mores.

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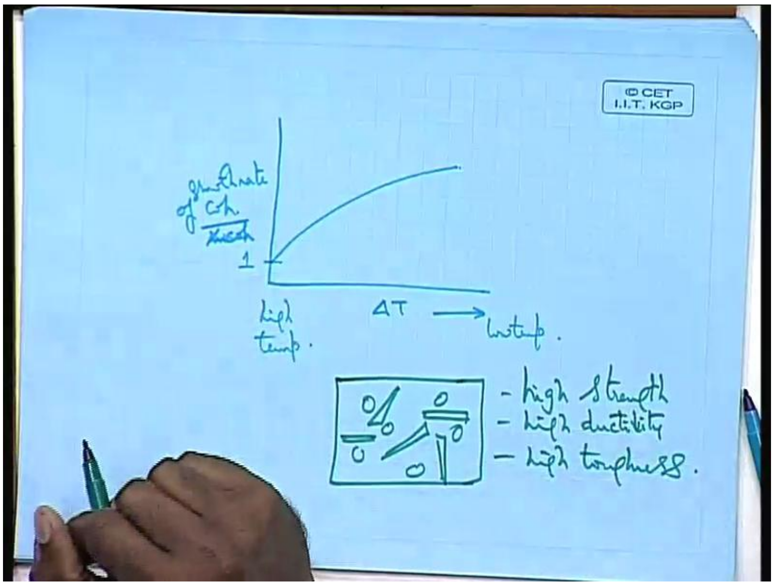

If you look at the growth rate of coherent versus in coherent precipitates. At low temperature if you are talking of delta T increasing; that means, this here high delta T means low temperature, low delta T means high temperature. At very low temperatures are high delta T. The growth rate of coherent precipitate is much faster. Because, the precipitation of in-coherent precipitates does not occur at high under cooling’s.

So, whereas at when you come to high temperatures at high temperatures the ratio between this more or less reaches equivalent to one. So, if you try to plot, you will get this kind of a situation. So, the tendency for the formation of coherent precipitates is much higher at high under cooling.

And when you come to low under cooling, which are very close to the transmission temperature. You have a greater tendency for the formation of incoherent grain boundary alerts you are mass. That means, the precipitation occurs near the grain boundaries, not within the grains. And then starts continue the growth occurs into the grains and then the morphology of the precipitate will be more or less sphericular not really a secular.

And they more or less grow in a symmetric fashion, into the grain boundary grain. In a more or less spherical kind of a situation. So, as result one can have a two stage precipitation process, where one can achieve both these type of microstructure. That means, you first heat it to a beta single phase region. Then, cool it suddenly to a temperature, just below the transmission temperature and then hold it some time.

So, that you have grain boundary coming out. And then before the precipitation is complete, you take out the sample from that furnace. And quench it to another furnace a low temperature furnace and hold it again there for some time. So, that the remaining precipitates come out as a Wigwam Staten type of a secular precipitate.

So, this is a two stage precipitation process or two stage annealing process, people have adopted in the titanium based alloys. To give you a combination of both, that you have some precipitates which are of this type and some precipitates which are of this type. We have a combination of these two type. Then, you achieve what you really are looking for the high strength, the high ductility and high toughness. A good combination, I would say I would not say all of them are very high, but an optimum combination of all the three. Under these circumstances it will not be a situation, that the toughness is very low or the ductility is very low. They will be reasonably high, when compared to any of the two microstructure that I have shown you before.

And in this way in alpha beta alloys people have been able to get very good combination of properties. And which are being used now a days for high temperature application up to at least about 550 degree centigrade or so… For particularly, the frame type of applications, where you need some formability. And high strength, this type of alloy defiantly are not useful for the high temperature jet engine type of applications. Because in jet engine type of application, you need more or less single phase alpha, because if you have a two phase microstructure, then the unless you have the second phase being very stable such as a disperse soids. We have seen in a nickel base super alloys. For example, eteria is added which does not dissolve back into the matrix.

So, for high temperature applications you really need precipitates, which do not dissolve back into the matrix. At high temperature, if they start dissolving back into the matrix. Obviously, you cannot use that alloy for a high temperature application. For example, here if you take the alpha beta alloy and put it at round 900 degree centigrade for a high temperature jet engine, then this alpha which has come out of beta during the precipitation. Obviously, will dissolve back into the beta and you get into a beta type of alloy. So, we do not use alpha beta type of alloys or beta type of alloys, for high temperature applications. Beta types of alloys why do not use we have talked about it in the last class, because beta is BCC.

So, we never use a BCC structure for a high temperature applications. So, that is why, if you want to high temperature mechanical strength. Good creep resistance for the jet engine type of applications, we need go for alpha type of alloys. For structural applications we go for alpha beta type of alloys. So, keep that in mind. Similarly, beta alloys are also useful for structural application.

But, single phase beta alloys because they cannot be heat treatable. So, there advantages are limited, when compare to alpha beta alloys. Alpha beta alloys can be really heat treated and one can achieve a much better properties. The other major titanium based alloys are what are called shape memory alloys.

Though there also other alloys, other then titanium based alloys, which are used for shape memory effect. The most popular alloy is a titanium nickel alloy, people call it as ((Refer Time: 18:51)). So, that is from where most of the work on the shape memory effect has come into picture.

So, let us try to see what are these shape memory alloys. First of all why do we call them as shape memory. And what is the basic requirements for a particular alloy to show a shape memory effect. And what kind of alloy show this kind of shape effect, let us try to see that.

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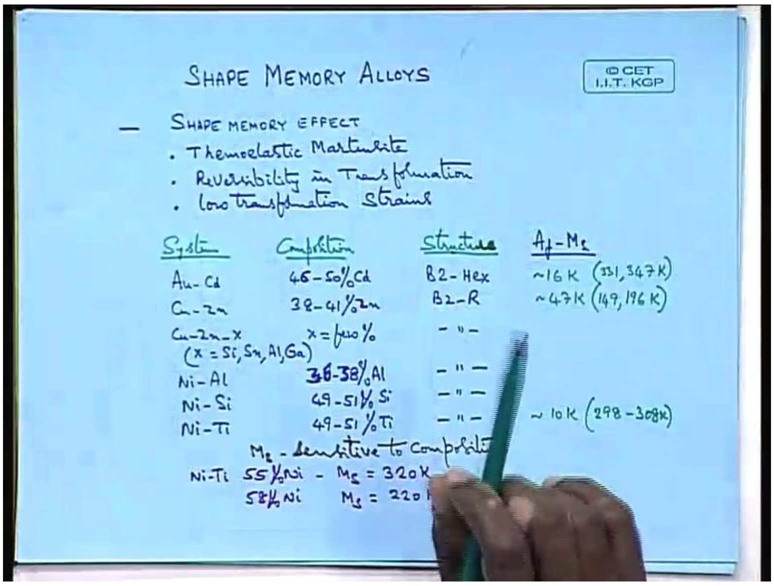

What is a shape memory effect first of all. A shape memory effect is basically that, where the sample remembers it is shape, which once under certain condition. When, it has been take to some other processing condition and brought back to the original condition.

For example, you take a titanium nickel alloy 50 50 alloy, 50 50 alloy has a what kind of a structure. Do you know TINI? It is a BCC b 2 type of ordered compound, it is a b 2 ordered compound. So, if you take a b 2 ordered compound it has a martensitic transformation, it under goes a martensitic transformation at low temperature.

TINI is one of there are so many alloys which show martensitic transformation. We know even steels show martensitic transformation. So, similarly TINI also shows martensitic transformation. But, the only differences is this particular alloy shows this shape memory effect, which the normal steels do not show. We will also try to understand, why the normal steels do not show it.

So, let us try to see what happens in this alloys. You take the austenite in the TINI, high temperature phase is usually we refer to is a austenite. Though it is nothing do with steel austenite. But, now a day's most of wherever a martensitic transformation takes place, all those alloys the high temperature phase is usually called as austenite, though it is not related to iron carbon austenite.

So, that austenite, if you cool it to below the m s temperature; that means, where the marten site start forming. And bring it to the martensitic condition. The marten site here is a Rambo hydrant type of marten site, Rambo hydrant structure. And this marten site is a real deformable type of a marten site, it is not very brittle like in steels, it is not very brittle. But, this particular marten site is deformable.

So, if you deform this marten site by a small amount. Let us say, you take a rod like this, in the austenitic condition, bring it to below the MS temperature and then deform it, bend it let say. And then once you have bent it below the MS temperature, bring it back above the AS temperature - austenitic Star temperature. Once, you come into the austenitic range again, the bent structure comes back to the normal position.

That means, the alloy has somehow remembered. What was its shape in the austenitic condition. And it try to remember that shape and comeback to that particular shape. Otherwise, usually when you bend a sample just by when you heat it, it does not come back to the same position is not it.

So, this is a particular property of a special class of materials, which are called shape memory alloys. And now a day's people refer to them as smart materials. This is the terms, which is used for most of the materials, which have some property, which can be kind of tailored and used for some advantage. For example, piezoelectric materials, these are also called as smart material.

Piezoelectric materials means, if you provide some electricity it deforms. And if you deform it, it gives you some electricity. So, all this kind of materials, where some physical properties are affected physical are mechanical properties are affected. Because of some changes which are taking place, inside the material which can be used for a to an advantage.

How we use it to an advantage, we will try to see it in terms some of applications of the shape memory alloys. And so this is particularly the effect that you see. And why does this occur, under what condition it occurs, does every alloy which under goes a marten site show this no.

First thing is for example, steels you take it. Steels if you take a Marten site, take an austenite bring it to marten site and start the heating the marten site. What happens to the marten site?

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It get's tempered. It transforms to a tempered marten site and it does not transforms to an austenite. So, the first and four most criterion for an alloy to show you, the shape memory effect is that it has to be a reversible transformation. The transformation has to be reversible. That means, I take a austenite bring it to a marten site and heat it back I should get back the austenite, without any intermediate steps.

See, even in steels if you ultimately go to above a 3 it will come back to austenite. Even in a tempered marten site, if you say sir no, no it also reversible because it is come back. If I heat this the marten site up to a 3 temperature, it will come back to austenite, these is no solution.

But, before it transforms to the austenite, it has already transforms to an alpha plus a either epsilon type of a microstructure or alpha plus cementite type of a microstructure structure. And finally and that alpha plus cementite is what is transforming into the austenite. So, this is not called as reversible transformation. So, reversible transformation is that, where there are no intermediate products coming out.

So, this is first and foremost criteria, that it has to be a reversible transformation. Second thing is, that this marten site has to be a thermo elastic type of a marten site. What is the thermo elastic marten site? Thermo marten site means, a marten site where when a austenite transfer to marten site, the strains that are involved during this transformation.

Because, we know whenever a marten site transformation occur, it is a shear transformation is not it. Whenever, there is a shear, there is some strain involved, these are called transformation strains. So, austenite to marten site transformation always involves some strain, and if this strain is very small in nature not more than about 8 percent.

Usually people have seen that shape memory effect always occurs, if the transformation stray strains are not too large. Why they should not be too large, because if they are too large. When you try to heat the sample, the strains are not completely recovered. The strain has to be small enough. So, that when you heat it the strain is recovered. And that is a crucial aspect of thermo elasticity.

So, thermo elastic marten site is that, that were this transmission strains are elastic in nature. They do not bring in really a major plastic deformation. And these strains can be recovered back, when you heat up. And that a typical nature of a thermo elastic marten site. And the third point should be, the strain should not be too large. In iron carbon alloys, the strains are too large. This is one of the major problem.

For example, in case of iron nickel alloys, if you look at the difference between MS and what is called AF or AS temperature. So, here we have four different temperature, we refer to AS. The MS temperature where the marten site starts forming, the m f temperature where the marten site is finishes formation. Then, when you are heating this marten site, this is one temperature called AS and another temperature called AS Austenite Start Austenite Finish.

Because, all these transformations the AS and AF, these are all basically thermally induced transformations. So, as a result as a function of temperature, the transformation occurs. And it starts at a particular temperature and complete transformation occurs beyond a particular temperature. So, there are four temperatures that are involved. So, if you look at the difference between MS and AS, this difference is very large in iron nickel alloys.

The reason is, because the total amount of strain that is generated in a iron nickel alloys is very large. So, when you try to heat it, you have to heat it to a large temperature range. Before all the strains are recovered and transformed back to the austenite. So, that is why usually iron nickel alloys do not show much of a shape memory effect. Whereas, the titanium nickel, the difference in the temperature is only above 10 degrees.

So, if you look at the various alloys which give you the shape memory effect. There are range of alloy mostly non ferrous. If you look at it, most of the ferrous type of alloy's, iron nickel to some extent shows. But, it as I told you the difference in the temperature is too large for many practical applications.

So, because of which... So, you can see the titanium nickel is one of the very crucial examples. The composition range I have given here 49 to 51 percent. And the transformation is basically B 2 to a Rambo hydrant type of structure. And the difference between these two temperatures is about 10 Kelvin. The MS temperature is about 298 and AF temperature is about 308 Kelvin. So, it is about just 10 degree.

But, what is important is, this is quite sensitive to temperature. If you look at the titanium nickel, if you change the composition, the MS temperature drastically changes. If you take about 55 percent nickel, the MS temperature about 320 Kelvin. If you take about 58 percent, just increase the concentration by 3 percent nickel. You will see, the MS temperature falls to about 220 almost 100 degree.

So, the this temperatures are very sensitive to the composition of the l r. One has to consider the composition very carefully. And a number of other non ferrous alloys,which give you this type of shape memory effect, gold cadmium is 1 where B 2 to hexagonal type of transmission, in the range of 46 percent to 50. And copper zinc alloys, where the beta transforms.

The beta brace you know that it is B 2 structure, B 2 structure transforms to Rambo hydrant. And copper zinc aluminum is a most commonly used shape memory alloy. Copper zinc anyway shows I told you. But, if you put a small amount of either silicon or tin or aluminum or gallium, it also shows to you a good shape memory effect. A nickel aluminum the N i A l and nickel silicon N i S i.

So, there are number of these alloys and what is important to notice most of these alloys. The shape memory effect is observed at inter metallic compositions; most of these phases which transform to martencitic transformation. And give you the shape memory effect are all mostly inter metallic's.

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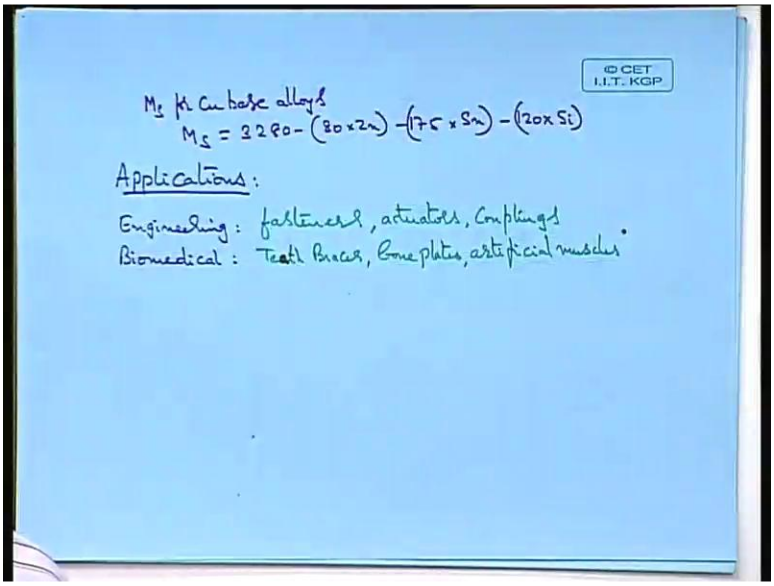

And ordered inter metallic's and these ordered inter metallic's will undergo. These thermo elastic marten site transmission. And which will give you this kind of shape memory effect. And this MS temperature as I told you is a function of composition in many of the alloys. Just if you look at the cooper zinc based alloys, if you look at the MS temperature.

MS temperature is a strong function of the composition as is showing here, MS is given by three 3280 minus 80 into zinc minus 175 into tin and minus 120 into silicon. So, you can see clearly, how strongly each of these elements. These are all atomic percent, whatever percentages of various elements shown here, these are all atomic percent.

So, you can see each elements almost very strongly effect this MS temperature. And MS temperature is very crucial to know, what is a temperature below which ((Refer Time: 33:16)). And if you look at the applications, the applications are very wide. We have engineering type of applications, we have bio medical applications I will also try to show you some pictures, that I have collected.

In the case of engineering applications, the most important applications are where you need couplings and actuators, particularly in sensors we will try to see some of them. And in bio medical applications, particularly whenever you have the fracture in the bones to the bone plates or teeth braces even. For example, artificial muscles when you have an artificial heart installed in the body.

So, the artificial muscles can also ((Refer Time: 34:04)) shape memory alloys, where at the body temperature they can contract and expand. So, whenever there is a blood pressure. So, based on the blood pressure one can have expansion and contraction. And that can lead to the typical blood flow in the veins of these artificial hearts. So, one can use them here.

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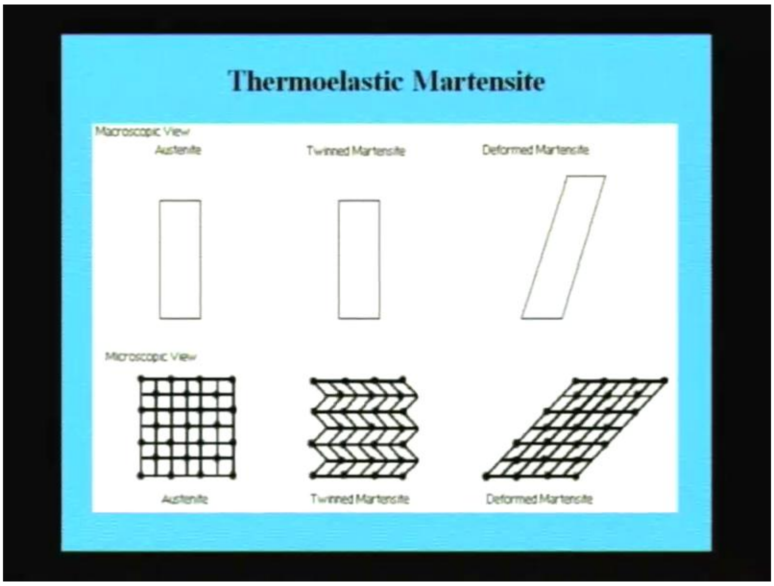

Let us try to see some of these here. What is this thermo elastic marten site, if you look at the austenite. Austenite in most of these things is cubic in nature, the B 2 type of structure, and the B 2 if you transforms to the marten site, thermo elastic marten site. The strains that are present during this transformation are absorbed into this marten site in terms of a lot of twins.

You get lot of twinning inside the marten site, were the strain is stored. And if you deform this marten site at temperatures below the MS temperature, the deformation leads to a shear type of deformation. And deforms this marten site and when you heat it back you get back this particular structure.

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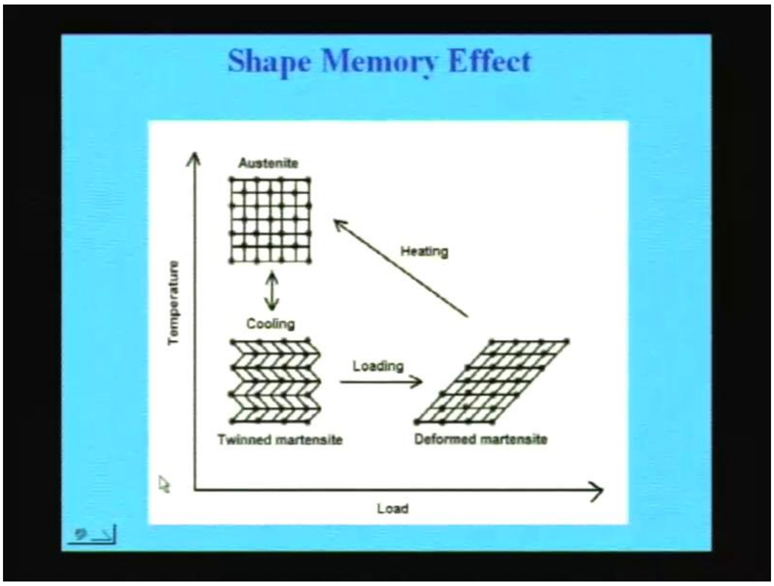

And how does this occur, a schematic picture is shown here, where the austenite at high temperature is brought to the marten site by cooling. And during this transformation, there is a lot of pinning that take place in sides the marten site. And when you deform this at temperatures below the MS temperature, this marten site gets deformed.

And this deformed marten site, if you start heating it, you get back this austenite. And whatever deformation that you have given is lost. And you get back this original shape and that is what we call it as a shape memory effect.

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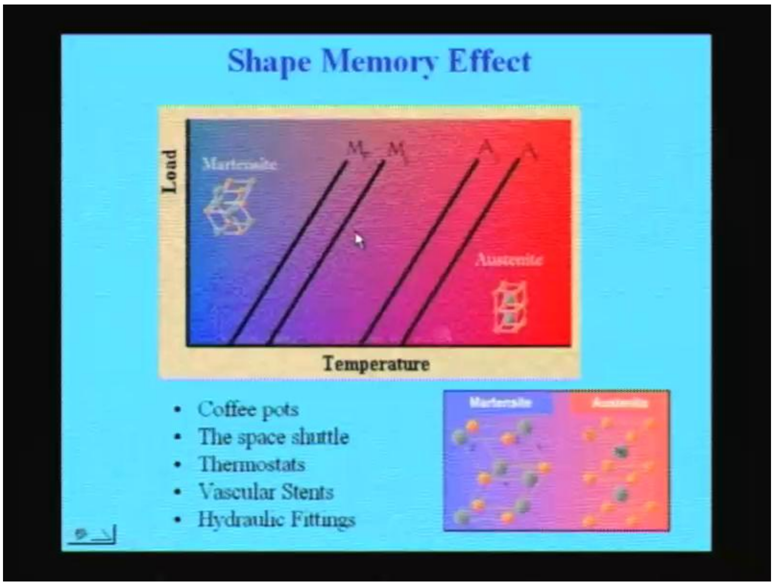

And if you look at the other way, you see here different temperatures are shows. The MS temperature, MF temperature, MS temperature, AS temperature and AF temperature, the four different temperatures are shown. And these temperatures are a function of the pressure. You all know, that whenever we pressurize the transformation temperature changes. What is this kind of principle called, we have talked about it thermodynamic.

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((Refer Time: 37:18)) So, from that you can when you load a material depending on the type of structure. So, the transformation temperature changes. So, here the transformation temperature increases with increasing load. So, if we look at the high temperature austenite, it is shown in the red color, because the temperature is high.

So, this austenite if you bring it back to the marten site by cooling it down. This marten site, if it is deformed and then heated back, you get the original shape of marten site of the original austenite. And retains, whatever shape that you have in the original condition. In fact, I had a few video clippings, I wanted to bring that somehow they are not working on this power point, may be some other time I will show you those clippings.

So, the basic structure is shown here, you can see it is the cubic B 2 type of structure, titanium occupying all the body corners, nickel occupying the body center. That is, a typical austenitic structure B 2 type of structure. And when you change it to marten site, it becomes the Rambo hydrant.

So, this is the typical Rambo hydrant type of structure, where you have the atoms occupying again the similar positions. But, the structure changes from the BCC type to Rambo hydrant type. And a number of applications are given here, where we use the shape memory effect, a simple starting from a simple coffee pots to a space shuttle, thermostats. And hydraulic fittings a different applications where we use this shape memory effect.

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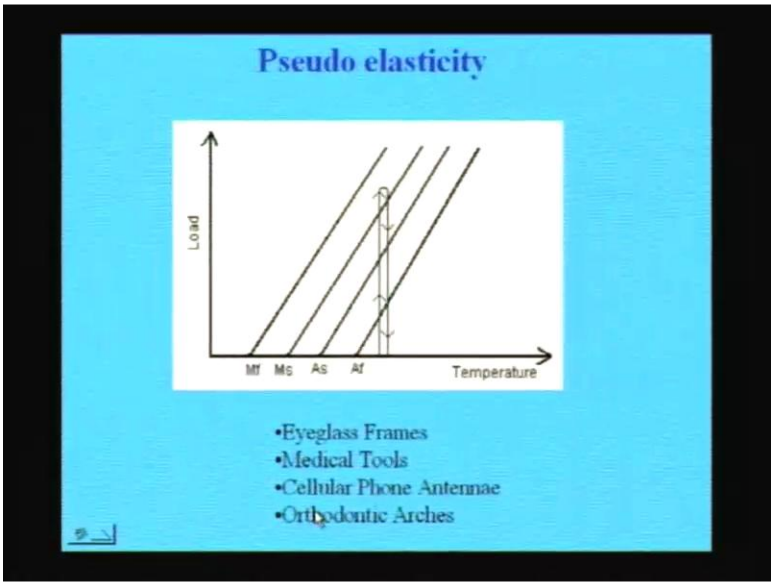

The other most important concept here, which is very similar to the shape memory effect is called pseudo elasticity. In a shape memory effect what we do? We take a high temperature structure, bring it to the room temperature. Deform it at true a brining to below the MS temperature, I do not know call it room temperature. Because, we do not know, where is the MS depends on the composition.

So, we bring it to below the MS temperature, deform it in the martensitic state. And then heat it back and we get the austenite and the original shape back. Whereas, in a pseudo elasticity what we do is? We do not change the temperature, we keep it in the temperature above the AF, where it is completely austenite. And start deforming the alloy.

When you deform the alloy increase the load, at a fixed temperature. The temperature is above the MF. And when you start deforming it, the movement you start deforming it, it becomes marten site. Because, deformation induced marten site comes into picture. And once, you come to a marten site completely, either above the MS or completely above the MF depending on your interest.

And then release the load, once you release the load. Then, the shape comes back to the original position. So, here there is no temperature involved, it is only the deformation it is involved. So, but the shape comes back to the original position basically, because the strains that are involved are elastic strains and deformation induced strains.

And these deformation induced strain, the movement you release a strain, it comes back. Because, the amount of strain is very small. Similar thing does not occur in the kind of steels. For example, in steels you take an austenite and deform the austenite. And we see that we also see deformation induced marten site formation. But, then you do when you release the strains, it does not come back to the austenite, because the amount of strains that are involved are very large in a steels. Basically, because of the carbon atoms which are present their, which occupy the octahedral positions. So, because of which the prevents, the marten site to come back to the austenite very easily. Whereas, here the amount of strain in that is involved during the transformation is small.

Because of which if you heat it, if you deform it to the marten site condition. And then release the strain it comes back. So, you can see vertically in the loading direction, we go up and the release a strain it comes back to the original position. So, this concept also is used in a number of examples. Such as for example, high glass frames, where the this kind of thermo elastic marten site, pseudo elasticity is used cellular phone, antenna. And orthopedic implants, ortho dental implants and other medical tools.

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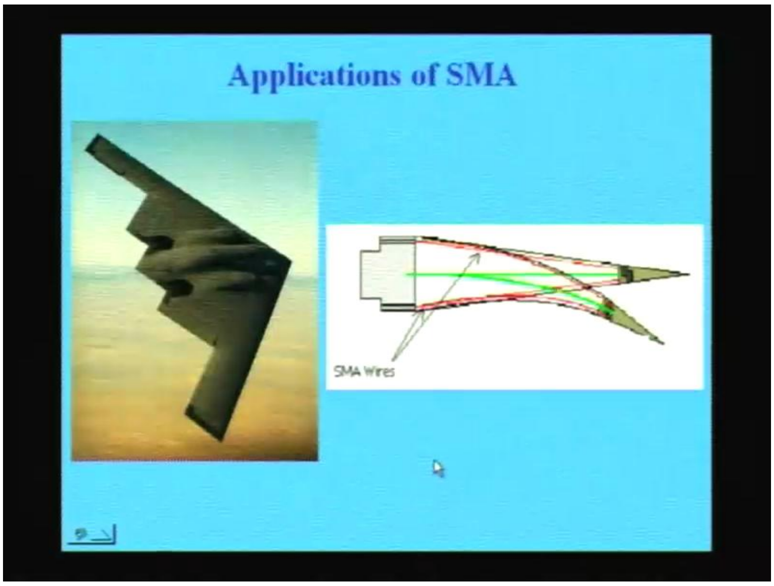

And some of the examples are shown here. This is one example, where we use a these materials. In A craft application, where you know whenever you have an aircraft, the actual maneuvering of the air craft. Whenever, you want to turn it or lower it or take it to higher heights. It is all done with these beings here, you have some kind of fins which keep on moving.

And these this movement is what gives you the drag and the lift. So, based on that you can have the raising or lowering of the aircraft can easily occur. Particularly during landing or during takeoff, these are very crucial parts. And this movement of this is usually done by hydraulics.

You have a hydraulic cylinders, which are used to either pull it up. The fins are raised up or brought down is done usually by the hydraulics. And you have heavy hydraulic pumps inside the aircraft, because of that. So, now-a-day's people want to use this kind of shape memory alloy guides, where the shape memory effect can lead to either movement of these fins in a downward direction or upward direction, depending on the loads.

For example, depending on the pseudo elastic nature of it. Whenever, you have a load the movement you give an electrical signal here. And that electrical signal transmits to that. And then that induces a some kind of pressure on the shape memory alloy. Then, immediately it transform to either a marten site or if it is already in the martencitic condition it transforms back to the austenite condition.

So, like that by change of the transformation from austenite to marten site, it is just by a phase transformation. We can have this whole fins moving either upward or downward. This is one of the application.

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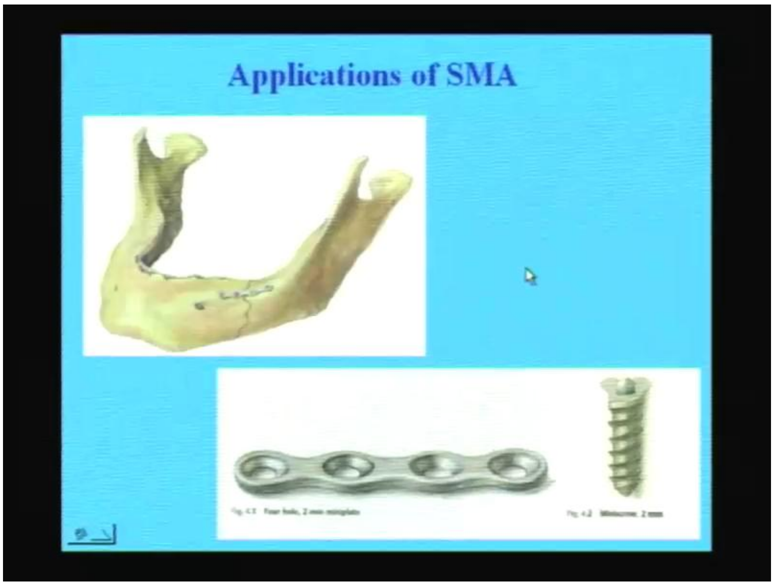

Another most crucial application is wherever the bones are the broken. Earlier also people use to put some plates like this. Particularly cobalt based alloys or titanium based alloy. Titanium based alloys are very popular for medical application. Particularly, because of their high corrosion resistance, titanium based alloys have very good corrosion resistance and good bio compatibility.

So, as result titanium alloys are used in all these application. But, what is the specialty of the shape memory alloys is that. So, the application here is simple, that let us say the bone is broken. You bring both the bones together put them together. And put a this kind of a plate there, which joint both of them. You drill two holes in this two bones and put a screw.

So, that that plate is held on these two bones, one on top, one on the bottom. The bottom one is not seen here. So, you put one at the top and one at the bottom. And then you hold it there for some time, let us say a 2 months are so. So, during this period the bone grows. And once these two get joined, then you do another X-ray and find out that both of them are joined. And there is no dislocation there is no crack there.

And then you can remove those plates. This is the usual technique, which everybody employed, till the shape memory alloys have been discovered. But, once the shape memory alloys have been discovered. The advantage here is that you can take the shape memory alloy, which is austenite at the body temperature.

And if you take this austenite to below the MS, which is let us a much lower temperature let us a 10 degree or so. What is our body temperature about 37 degree centigrade. So, you take the sample a alloy to a very low temperatures. At the where the transmission occurs to the marten site. And then you put it into this bone, you do a surgery and then put it there.

And the movement this comes back to the austenite temperature. Then, there it shrinks the marten site once it goes marten site is a when it goes to austenite. Austenite is a structure which is more close back then the marten site. So, there is a shrink. So, once it shrinks what it happens is, it pulls both the bones together and then holds them together. So, there is a kind of a compressive strain.

So, if you think of this plate, the plate shrinks. When the plate shrinks the two bones are brought together. So, that they are held together very closely. So, that this what is called curing occurs much fast. So, that is one of the advantages, where people have been using the shape memory alloys to a large extent.

And now a days is very common to use this shape memory alloy. So, only factor that one has to consider is a what is the bio compatibility of this alloy, lot of work is being done, where people. At the same time one cannot really do it experiments on the people. So, they try to do experiments on the animals or... For example, now a day's there are synthetic liquids available which are for example, what we call the body fluids.

So, whenever the shape memory alloys is kept inside your body, it experiences lot of body fluids is not it. So, these body fluids, whatever is there P h value. And whatever is a concentration, this kind of things have been simulated outside by chemicals. And then in some such chemicals, people try to keep these shape memory alloys for years together.

And check whether it is gets any corroded or not. And then try to see whether there is any stress corrosion cracking kind of situations. So, all this are being studied before it is actually implanted into a sample into a human being. So, lot of people have been working.

Another type of implants are dental implants. Particularly, whenever your jaw is broken. See, one important thing about dental implants is that, the type of implants that we use for dental applications are entirely different from what you use in a bone type of application or anything interior you are body, because interior of your body, the conditions are more or less the same. Throughout your kind of life or in a particular day, if you consider it is more or less the same condition, whereas in a dental conditions, the conditions change almost every minute. Just after this class you go for a cup of tea, you take a hot tea. So, immediately if you are crazy you go to ice cream parlor, you take a ice cream let us say. So, you see all kind of and also the type of food, that we take one day we take a very sour food. Let us say one day we take a hot stuff.

So, all kind of the P h conditions of the things the temperature conditions of the food, that we take are keep changing vary widely. So, because of which the materials that we going to use there, should be compatible for all these conditions. So, that is why people are very careful in choosing materials for dental applications.

Particularly, titanium based alloys are ideally suited for all these applications, where they have excellent corrosion resistance under all extreme conditions of body conditions. Under different P h levels people have tried, and seen that they are very good. So, that is one of the major areas of titanium based alloys, in addition to the aircraft. The basic starting point for titanium based alloys was the aircraft applications, where we have seen already where we use. And the recent applications are more on the bio medical applications. Particularly, dental implants or bone implants or... For example, sensors where you need shape memory alloys. We stop with this.

Thank you very much.