Principles of Physical Metallurgy

Prof. R. N. Ghosh
Department of Metallurgical & Material Engineering
Indian Institute of Technology, Kharagpur

Lecture No. # 40

Ultra High Strength Steel

Good morning, today we will talk about alpha high strength steel. In the initial lecture, we did mention that strength of metals as several orders of magnitude less than it is ideal strength. So, the ideal strength we derived is of the order of g by 30; where g is the cm modules. However, in reality we find the metals deform at a stress much lower than it is ideal strength, and this we learnt that it is primarily, because of the presence of crystal defects like dislocation. If it is possible to produce defects free crystals we do in fact approach these ideal strength and which has actual event found in (( )), which have filamentary crystals, which very small dimension, which is virtually dislocation free. But these kinds of material, they are not useable as it is, so is there a way of improving strength of metal, and particularly today we will see, how strength of steel can be increase all most to the order of magnitude of ideal strength of metals.

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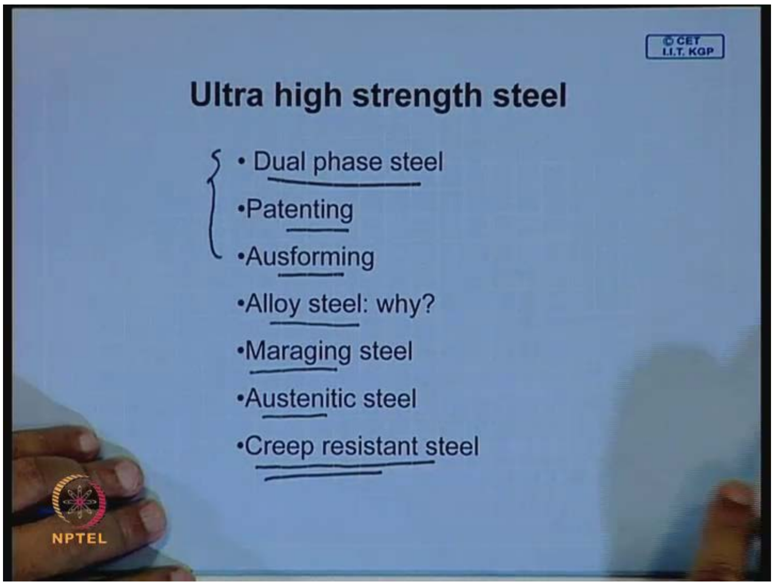

So, under this we will talk about several techniques, which have been a plat and we will talk about a few is; dual phase steel, will talk about is special process called patenting, will talk about ausforming, and again many of these cases these using these, it is possible to attain very high level of strength, even in plain carbon steel. Now, the question then comes up, why do we then have go for alloy steel, and unnecessarily increase this cost. Because most of the alloy additions, which have made the quite expansive, we will know why do we go for alloy steel. We will talk about to different class of the alloy steels, which have very high strength, and some very interesting property, we will talk about maraging steel, we will talk about austenitic steel, primarily we will talk about its steel laze property, and also we will know; however understanding of the principle of physical metallurgy, it has been possible to develop the type of steels; creep resistant steel, which have been used in several high temperature components.

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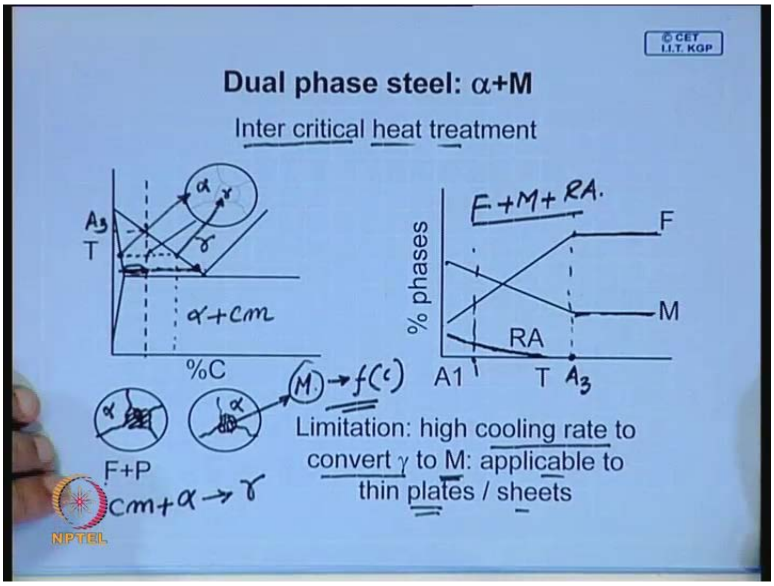

Now, let us talk about this dual phase steel. In a dual phase steel, what we do is a normal heat treatment process we heat, suppose this is the composition of steel, this is the part of the tarrant carbon diagram; this is austenite, this is ferrite plus cementite (( )). So normal structure is something like this of this particular composition, you will have politic region, and you will have ferrites; this are ferrite frames. So it is made up of two distinct regions, this are the primary ferrite, and this is pearlite. Now, when you heat it about this temperature, then what happens; these pearlite, the cementite dissolves in the neighboring; a cementite reacts with ferrite, and gives you austenite; and this reaction take place at these interfaces, and gradually the entire; this is converted in to austenite.

So what you have now, here it will be alpha that means ferrite; plus austenite. So it is duplex structure, you can also see the composition, this point will be giving the composition of ferrite, and this point will give you composition of austenite. Now, what will happen, suppose you quench from here, then what you will have is this ferrite parts they will remain unchanged. But this austenite part will convert in to martinisite. And then what you will be left with instate of ferrite pearilte structure; you will get ferrite martensite; and this martensite since it is carbon contains is high; it will have very high hardness, so you have a compost material short of thing; you have two face duplex structure and so this is advantage of this inter critical heat treatment, and this can be implemented in mass production as well; and what you see the depending on the temperature at which this inter critical heat treatment is given even have different amount of martensite.

You go higher; so if you go beyond this point, this will be zero; almost time in approaching says not zero, so what will happen, beyond this it will be totally austenite, and if you quench a part of it will convert in to martensite, and part will form ferrite. So, if you quench directly from here; because it has low carbon steel, it has low harden ability even, if you quench it very fast you may not get a completely; if you quench from here you may not completely martinsitic structure.

So this means this is the critical point, so this is A 3, so this, if you say this is A3; so if you go above A 3, then that is not match of change you have very small amount of martensite, and it may have mostly ferrite, this is percentage phase whereas if you a inter critical heat treatment is given here then you are likely to have some where here, then you are likely to have here that amount of austenite amount of austenite will be proportional to this region this line amount of ferrite it is this, but this martensite, so amount of martensite. So, this will be that equailburium amount and as you go up that among the martensite will changing, and also what will happen this martensite will have a much higher a carbon contain so therefore the m s temperature is likely to be even possible little be m f certain we will be lower than the room temperature. So even if you quench your likely get some amount of the retained austenite, and this will goes on decreasing, so you are total structure over here, it will consists of ferrite and this is inter critical heat treatment temperature, it will ferrite martensite plus retained austenite an as you increase the temperature amount of retained austenite goes on decreasing, and here off course you will get ferrite and martensite. But advantage of having a duplex somewhere in between there is a possibility we will get a martensite strong a martensite because we know the strength of the martensite is a function of carbon content, so it is likely to have much higher strength. But limitation of the dual phase is the high cooling rate is to be a adopted to convert that austenite to martensite in plain carbon steel, and it is applicable to thin plates and sheet, so this high limitation stays.

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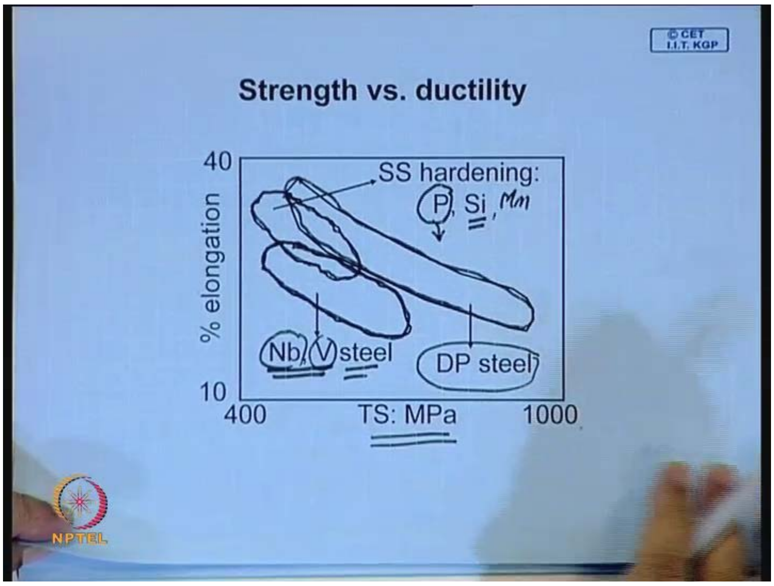

Now, dual phase steel what is the most attractive is, this has; this gives I mean better combination of strength, and toughness; because many application we know the is not strength may not be enough, it must have very high degree of ductility. Look at this; this is the region which of the dual phase steel, and how does it compare with conventional steel; conventional steel means strengthen mechanism; is a solid solution strengthen and some of the solid solution; phosphors has a very high degree of; little phosphors can significant link increase the strength, but it is aggregate; is the makes steel brittle, so these are the problem. Silicon is the common solid solution strengthens, manganese off courses does improve, but it is not as strong as phosphors or silicon. And grindry finding is the key strengthen mechanism in case of micro alloyed steels so where graindry finement we look that it critically, so navobiam, and vanadium, so carbides ,and nitrates of these steels, these are the key conteachwent which refine will helps or which inhibits arsenic drain growth. And you get a very find structure so compute all this, this has better combination of strength, and toughness, and it also has good formability so that is why there is a special attraction for dual phase steel.

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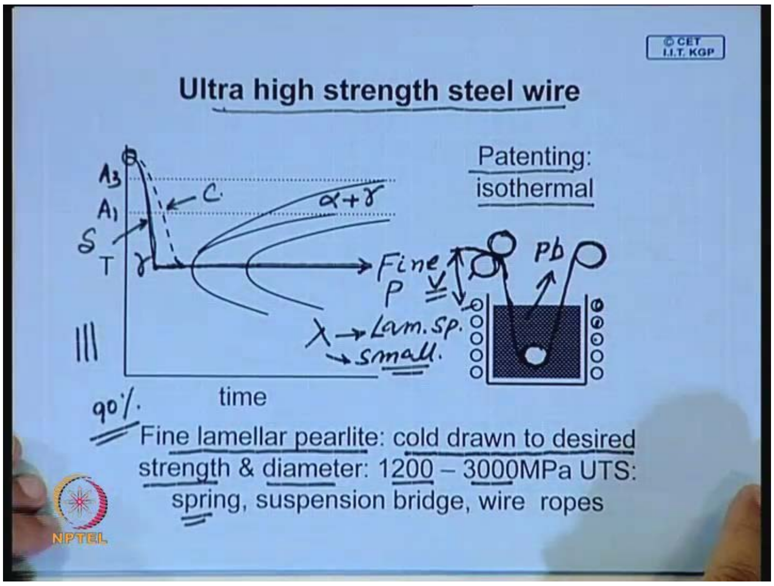

Next, let us consider a special heat treatment process called patenting, this is isothermal heat treatment process, what; and it gives very ultra high strength steel wire, this is used to produce high strength steel wire if we look at the time temperature transformation diagram of steel. So this is the A 3 temperature and this is A 1 and here if you ferittie plus austenite; this side is austenite. And what we thing to do is, we cool the steel from above from the austenitic region when it is austenite. You cool it almost to the nose here, so this is the temperature of the surface which will cool fast, this is surface, and this is core, and you maintaining in a bath an liquid bath consisting of mostly it is let and if you have a little bath this whole time may help in making the temperature uniform, and allow it to cool I mean allow it to transformation to completion at the same time temperature.

And what we trying to get, is fine pearlite; so that lamellar spacing lambda; the lamellar spacing is very small, lamellar spacing is really small. And under optical micro scope the pearlite will not resolve; so the normal pearlite you do series kind of lamellar structure, but main idea is, if you look at in a standard; in a optical microscope; standard optical microscope, and may be you will find that most of this pearlite modules are not resolvable. And how it is done, so these are some this through is guide rules and this is an idle guides, so this is the lead bath mol tent lead and this passes through here you may straighten, this is a role. And, sometimes you can heat it also this.

You can apply some voltage between this and this; and this is a lead bath, and these are heating coils and you can also have some; this can setup easily in a laboratory this can setup easily in the laboratory and you can apply some voltage and then the wire gets heated up and this temperature is about A3, it comes in to the lead bath, and this is the just guide idle role, and this wire comes out and it coils here, and why this treatment; it is possible to get extremely find lamellar pearlite.

And they have the excellent drawing property that they can we cold drawn to desired strength and diameter, and you can get strength as I look at this of the order of g p a giga paschal strength you are getting, and these are use for very high strength applications like spring then suspension bridges were height and side wire ropes, and strength will increase definitely as the percentage carbon grows up. And in fact the lamellar when you give such a high cold working so maybe say 90 percentage cold work these lamellar spacing is you know the even smaller, and in fact with transmission electron microscope people have seen they come out be of an nano scale dimensions this spacing as result search a large deformations, and that is responsible for such high level of strength.

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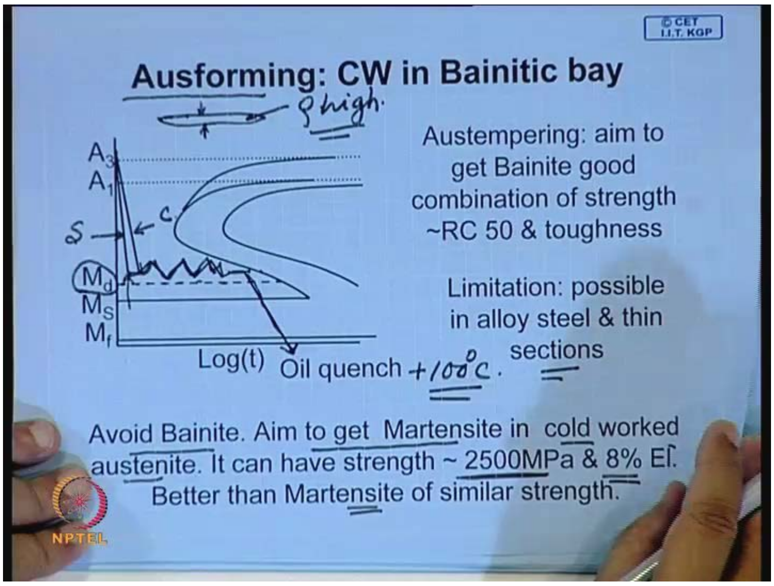

Now, let us look at another space cell forming process called ausforming. Now during a micro alloyed steel; what we found out is, if you work austenite at low of temperature, that austenite will not re crystallize and these austenite grains in particular one direction, and if you deform one direction, these grains become highly long it is least so in this one directions, they become extremely as small dimensions. And now they do not re crystallize; so they will also have high dislocation density, so row will be high; dislocation density is high. Now, if you cool if you cool austenite to a region we haves in most steels they have a (( )) way, and this way if you are able to cool at this temperature and this is the core temperature, and this is the surface temperature.

When you cool here, and then you give walking at this region; and here your hold time is sufficiently long, but if make sure you do not go too close to M s, so in fact this working has to be done at a temperature higher than M d temperature. This means that if you work, then the martensitic start temperature goes up the deformation, this is the martensitic temperature for certain percentage of deformation, so do this give cold working above M d. And after the cool working is over, and before this is the bainite starts forming you quench the steel, and after this; it is necessary to give some tempering may be hundred degree centigrade you temper to relive internal stresses. But the key thing is; is avoiding bainite, and you get martensite in cold work austenite.

So austenite is also very hard within the that also you get finer; much finer martensite. And this dislocation density will be much higher, and here you can attain strength level is quiet high yet you will have sufficient ductility, which is not possible in martensite of similar strength. And we will see that although this type of heat treatment can given in plain carbon steel of an; it is not show easy to do, so because of section size limitation. But if you go for an alloy steel possibly you can go to a higher. In alloy steel possibly section size limitation may not be that critical and we will look up about it.

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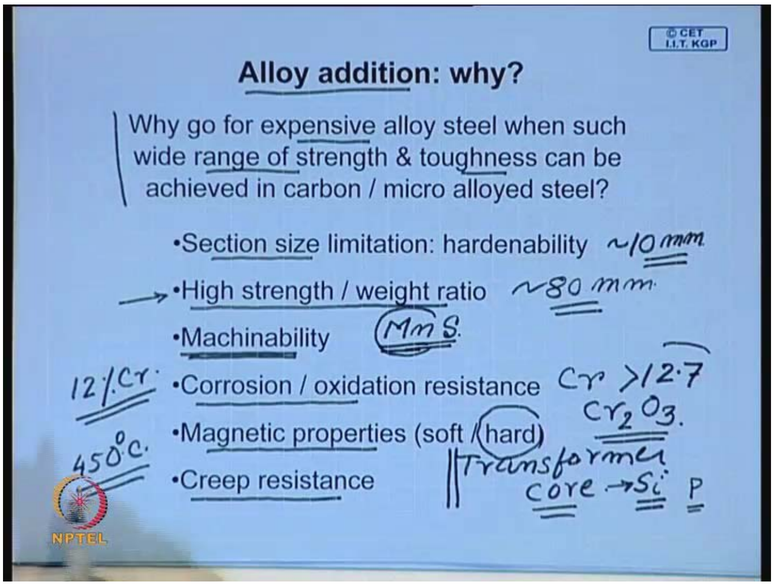

Now, let us look at why do we need alloy addition, say when we can why go for such expensive alloy addition, when such a wide range of strength, and toughness can be achieved in carbon and micro alloyed steel. Is it really necessary, because alloy addition always will make steel expansive. Now, major limitation is; in plain carbon steel they have poor harden ability, and you have section size limitations a plain carbon steel as say may be even, in the case of infinite quenching is extremely high rate of quenching; say ideal quenching you may be able to get through thickness hardness that means fifty percent of martensite at the core up to latter, say may be depending on carbon contain may be a proof certain mille meter.

So many application, this is too small; say suppose one application that comes to mind right now, later say; this a landing gears of a craft, so this is the part of the air craft it has to fly, so obviously your aim will be to use very high strength material. So that strength to weight ratio is high, so it does; I mean so that structure is light it can fly. And in this case this dimension of this may be of the order of eighty mille meter dia. So, imagine so it will be impossible we know that best property; that you can get in steel is trough by hardening, and tempering; that is temper martensite gives you the best combination of strength and toughness. And this steel must have high strength as well as toughness. So it is no way you can achieve this of such a large size.

So, here alloy addition becomes a must. And some time to get a certain very specific properties, many applications the nuts and bolts were to make then you they are to be machine, so this has to be a material should be machinable. So normal steels the machinability can be improve significantly by, not only by heat treatment, say, if you have globular cementite machinability is higher. But most cases in steel bulk of steels which goes for nuts and bolts may not have high amount of carbite, so there machinability is improved by adding some inclusions, particularly in any case to take care of sulfur we add manganese, and you form this manganese sulfite inclusions.

In fact for machinable steel intentionally they are re sulfuorise, sulfur is added intensely and you little more of manganese to take care of sulfur. And the presence of the manganese sulfite inclusions gives this steel good machinable property. So, that means not only this hardness limitation, a harden ability limitation, but also to gave certain very specific property you need to add some alloy elements. The another important property the corrosion and oxidation resistance steel; it rust, to product it for rusting, you know we use many other technique as well like coatings you galvanize the steel to protect it for most of the steel application your galvanize steel product it for rusting, but many cases this may not work.

So, you may need to improve its corrosion resistance, to improve corrosion resistance you had set an alloying element, and one of the most common alloy element is chromium. If, it is present in dissolve form is greater than around twelve percent, so twelve point seven to be specify. See, if it is around twelve percent; more than twelve percent chromium, in that case, on the steel you have a protective; thin protective coating of oxide, which makes steel stainless. So, all stainless steel will have a minimum of twelve percent chromium, and this chromium must be present in solid solution. Similarly, magnetic properties; to improve magnetic properties, say many application steel as a known for its magnetic property it is magnetic below the curry temperature.

And, one of the main application is, let is a transformer core. And, here when it is convert you know increase the voltage low to high; high to low, this transformer in other core gets heated, and this is known as hysteresis laws, to cut down the hysteresis laws of an in steel, we use some special alloy element particularly silicon. Some steel you also add phosphorus electrical greed steels, so you need to get certain specific property. Similarly, to get a hard magnetic property transformer core is the soft magnetic.

Similarly, for hard magnetic property there will be other elements to be; special elements to be added. So, that means alloy additions can give an added necessary to gives improve certain specific properties. Another major application of steel is in power plants. And, power plant, say stream power plant say, boilers where the steel has to be used at temperature above say, let us say four fifty degree centigrade.

So this case, creep becomes and of the important feeliyo mechanism. So, in this particular case also you need to have some alloy addition which gives it a better corrosion; a better creep resistance.

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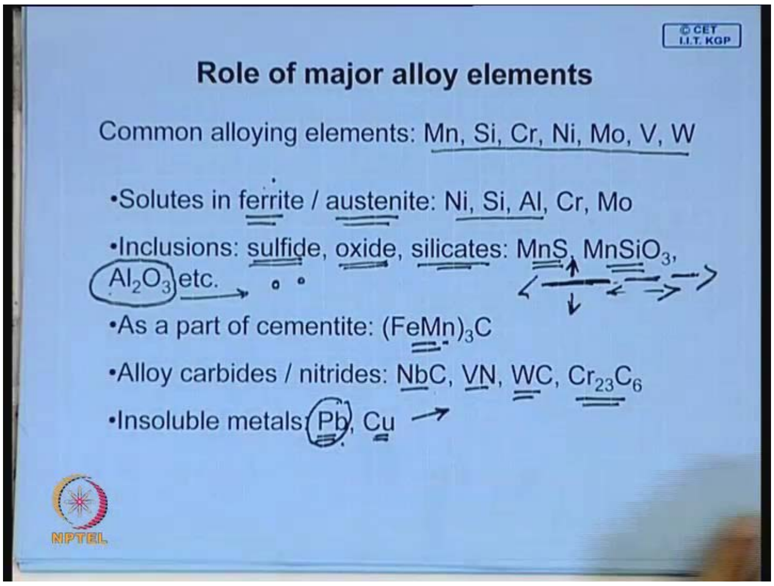

Now, any add alloy elements to steel; where does it go, and what is the role that they play, I think this will vary from element to element. So, here are some common elements which are present in steel. This list is binomial (( )), that can we several others also possible. But these are the major alloy elements, and these alloy elements either maybe present. So, many of these bulk of the steel which are (( )) it is a ferritic steel, but bulk of the steel that we used they are ferritic steel. And most many of these alloy elements they are soluble to certain even, if it is too limited extended, they are soluble in ferrite and in high temperature free austenite also they have some degree of solubility. So, they will be present as solute element in substitutional solute element, and ferrite, and austenite.

Some of the elements that you add, you know they react with some of impurities which are present during the steel making stage; there will be oxygen; it reacts with oxygen for oxide. There will be some sulfur; reacts with that sulfur, and converts into sulfide. And some form there are silicon is also present in steel, some form silicates. Some examples are given here manganese sulfite, manganese silicates, so these are possibilities, you can also have oxides aluminum we have seen is used as the deoxidizing agent, and it gives fine grain steel, so alumina is also an inclusions, and some of these inclusions they are; they deform (( )), and so these elements you know manganese sulfide, if it is present they will get elongated is silicon, and presence of this elongated inclusions makes the property directional, say suppose if there is an inclusion like this; so in this transverse direction it will have lower strength.

So it will not a fix strength in this directions along the longitudinal directions, but transverse properties particularly ductility they get affected, they have they also difficult to well because of these inclusions they give dice to the defect commonly known as lamellar theory so there should be some ways if these are that inclusion control becomes necessary shape and size of inclusion control is key to improve (( )) properties like the weld ability or transverse strength, where is these are hard particles they are present as globules. Some of the elements they may dissolve in the cementite like this, and many elements we have seen add nayobiyan which forms carbide, nitrites like vanadium nitrate, tungsten also forms carbide, molly also forms carbide, and then chromium also forms carbide. And there are certain metals which are added like lead copper they are insoluble so they are present us globules of lead or copper. Copper is added to some precipitation harden able grade of steel, hsla steels and lead is added to steel to give it good machinability.

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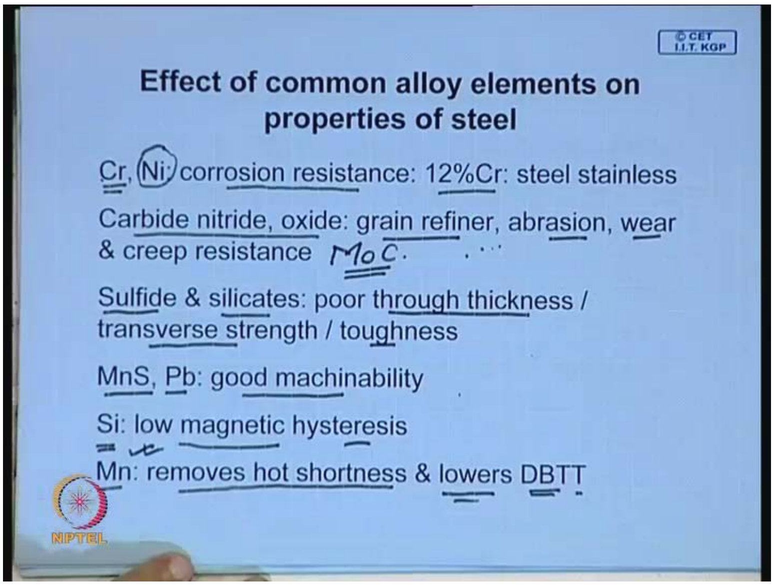

Now, few of the common alloy elements affect of which is listed here like chromium known for a corrosion resistance we have twelve percent chrome; steel become stainless nickel also improves the corrosion resistance particularly in acid: sulfuric acid environment. So, many of this stainless contains both chromium, and nickel, and few add a very high amount nickel you can make austenitic phase stable at room temperature. And we will talk about sub sequentially now, carbides, nitrates, and oxides; they act us grain refiner. If you have, say tungsten carbide that will add to abrasion and wear resistances. Some of the carbide like chromium carbides are particularly MoC: molipdinam carbide, they add to some carbides, add to creep resistance. This precipitates if they form along grain boundary, they actually inhibit grain boundary sliding and improve it is strength.

Similarly, if you have sulfide, silicates they give poor through thickness properties or transverse strength, and toughness. It also gives problem with weld ability. These inclusions we just mention they give good machinability; silicon low magnetic hysteresis. Addition of manganese, it removes hot shortness; we it did talk about it problem related to sulfur content steel. Sulfur aggregates to grain boundary, and if manganese is not there it will form with addend sulfide a low melting heated which makes steel; gives steel it is poor hard work ability, and this is known as hot shortness. Addition of manganese is extremely important to lower ductile to brittle (( )) temperature all cryogenic greed of steel will have sufficient some amount of manganese.

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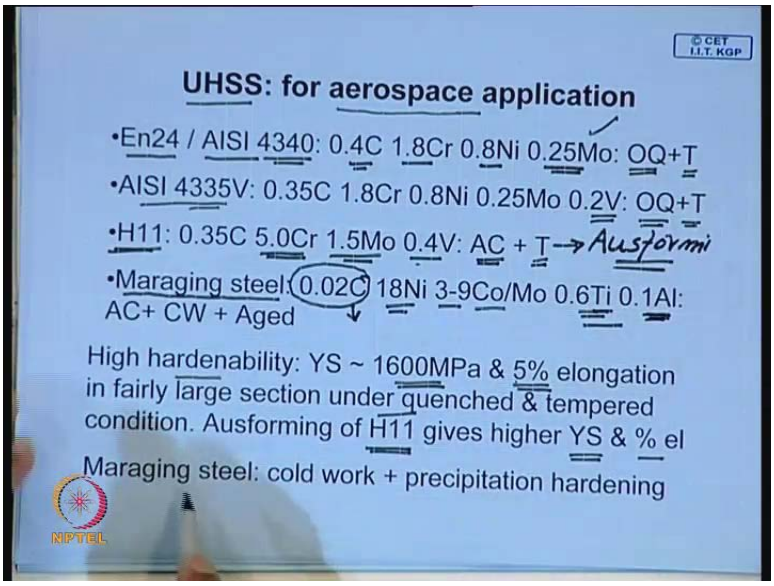

Let, we look us at few common alpha high strength steel. And many of these potential applications obviously they will have show high alloy element their expansive and but never the less application like, aerospace application where cost may not be major limitation. Because one major criterion is structure should be light, and it should be able to fly. So, this is the composition a very popular grade is En24 or AISI 4340 by this; it is know these are the composition 0.4 carbon, 1.8 chromium, 0.8 nickel, 0.25 molly. The molly takes care of many of this steel, when you add this alloy elements they have a problem of the temp of brittleness; addition of molly overcomes that brittleness and it is used in oil quenched and tempered condition.

So because of this alloy addition it has a good harden ability by oil quenching you will be able to harden through and through of a particularly this landing gear of applications this is very useful. There is another grad which is almost based on that vanadiyam addition adds to the strength. Here also the treatment is similar oil quench, and temper. Oil quench from that austenitic temperature range and obviously we look for fine austenite grain we do not heat it to higher austenizing temperature. There is the great called another alloy steel which has a much higher alloy element and so much of molly present you know makes this benthic be very long you know this type of steel, even if you air cool possibly you will get martensite, so you can air cool, so your quenching stresses problem are not there, and then you give temper, and it can also given ausforming, and by this you may get even higher strength and toughness properties.

Another greatest steel we will talk about it let us separately maraging steel here this has a very low carbon content, but high nickel, and you have some amount of cobalt, molly and some precept; to get some precipitation you get titanium, and aluminum. Main thing is you look at that carbon content; martensite is hard, because of carbon, and if you reduce carbon to this level definitely the martensite will be soft this martensite you can cold work so they may not have that high hardness, and it is aging when you age, so these are the elements, which develop some coherent precipitates in the matrix, and because of the formation of these fine precipitate, it strength goes up. Now all of these steels, so in this case off course have high alloy element, so they have high harden ability and you can always get strength of these order of g p a order you have five percent elongation in fairly large section. And, as I mention here this is amenable to ausforming and you can event get even higher yield strength, and ductility. The maraging steel we mention that here, the martensite is soft, it can be cold work, and then it can be given precipitation hardening heat treatment.

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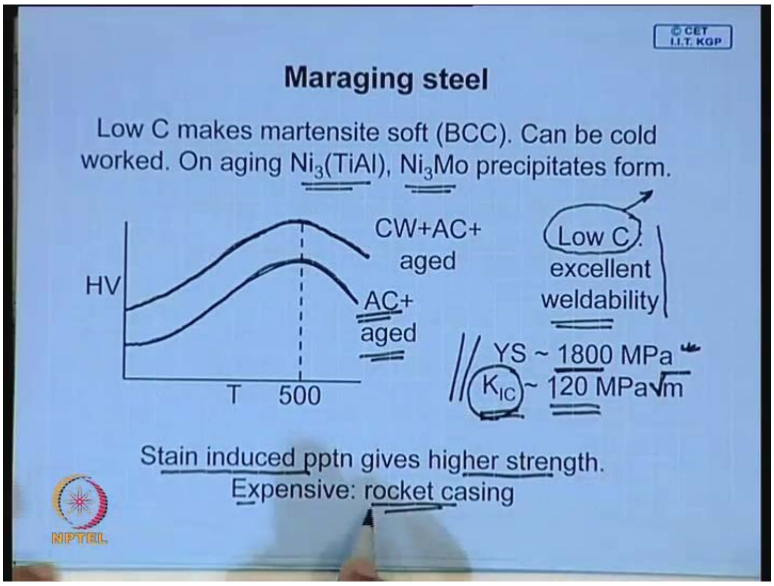

And typical, and when you give these hardening treatment, aging treatment the hardness goes up, if you do not give work; if you do not give any cold work then possibly the hardness increases like this. Air cold plus aged; whereas, if you cold, work and then aged then martensite; then that is the in that case, and the cold work martensite when precipitates form it gives much higher level of strength. An on aging this are the precipitate that form, and they have, because of low carbon content, they have an excellent weld ability, we will see while latter that the carbon in the mean alloy element, which is detrimental, which makes the steel difficult to weld.

So, good weld able quality steel always attempt is make to bring down the carbon content, and here the strength is extremely high it also have very high fracture toughness we did talk about K one C which is the major of fracture toughness. So, such high level of fracture toughness 120 MPa root meter square, and 1800 MPa strength is un hard of; so this the special greed of steel, so here you have strain induced precipitation, and which is responsible for its high strength this is no doubt expansive you have eighteen percent nickel, the nickel is most expansive amongst the common alloy element which are added, and but it is a unit material for like rocket casing; aerospace application.

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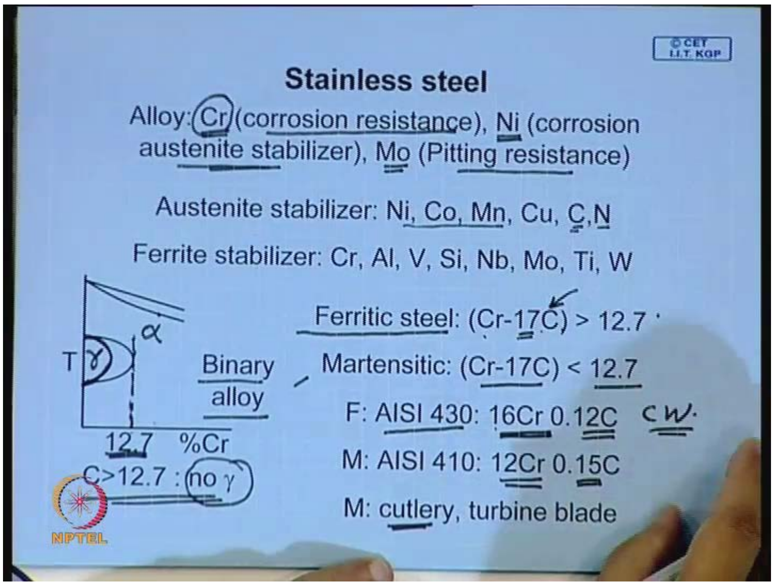

Now, let us talk a bit on stainless steel now you have seen main alloy element which is gives strain less is chromium you must have at least twelve percent chromium to form productive coating of chromium oxide. Along with that we also add to improve corrosion resistance nickel, that also austenite stabilizer we will see that even added certain amount of nickel then the steel become austenitic, and we add molly to give it pitting resistance. Some of the common austenite stabilizer which are listed here, even carbon is called carbon nitrogen; they are also good austenite stabilizer. Now, a quick look at this the ferritic steel; this the chromium; herein chromium, binary diagram, it is known as a gamma loop forming element. So, here you have ferrite, some time call it alpha or delta does not matter. So, this side is ferritic and here, so if you amount of chromium goes beyond the critical limit in that case if you heat the steel herein chromium alloy, it is remain ferritic until it is melts.

So you cannot form austenite, so if you hot too much of chromium then the steel cannot be harden given martensitic by quenching, the question of getting martensite does not arise, because you are not able to reach this austenitic state, so this is the one important point you must remember, this is binary alloy and this compotation is quiet important, and this gamma loop is around thirteen percent, say if it is greater than 12.7, then it is ferritic until it is melting point. So, this is important to remember, if it is greater than 12.7 that you would have no chance ausforming austenite.

So, if you have stainless steel were you have carbon which is the; you have seen this is a austenite stabilizer so if you have some carbon in the steel effective chromium concentration goes down. So, this is the factor, seventeen times carbon contains, so if you have point one percent carbon means, you add to this one point seven, so thirteen plus so two; around fifteen, so if this is greater than 15 chromium, in normal steel will always have some amount of carbon, so if it has around point one carbon, if chromium is greater than fourteen or fifteen, then you do not expect austenite to form, and this type of steel is known as ferritic steel.

And it will be stainless because it has more than twelve percent chromium in solution and if this is less than this then we call this steel as a martensitic rate and common ferritic steels, and martensitic steels say compositions are given one particular compotation is 16 chromium 0.2 carbon and this case as 0.12 carbon even find it will satisfy this relationship and this will be ferrittic it cannot be given any hardening treatment only way you can harden is some solid solution strengthen of cold working. Whereas, if you have in this particular case twelve chrome point one five rate so this is the martenstic stainless steel it can be heated to austenitic region and one quenching, so you get martensite. So this is steel commonly used for cutlery some of the turbine blades also in engine turbine blades are made up of this type of steel.

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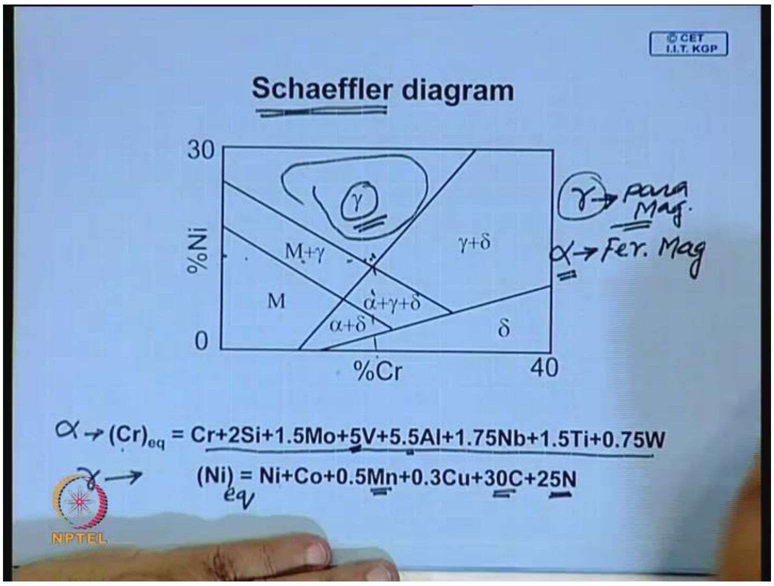

Now, to look at whether the steel; what will be stature of the steel; whether it will be ferrittic, weather it will be martensitic; are in the extreme case will it be austenitic that is represented very well by the diagram called schaeffler diagram so all alloy element can be grouped in to two parts, one is rich stabilize ferrite, and another is stabilize austenite. And, what you can find out; you can find out nickel equiv valiant or chromium equiv valiant, so. this stand for all ferrite stabilizer so factors which are given here, so some of the elements which are known as very strong ferrite former that is the temperature in which ferrite is stable; look at vanadiyam, aluminium, they have very strong ferrite former. Similarly, there are certain other alloy elements like manganese which stabilizes austenite. Carbon is the strong austenite stabilizer, so also nitrogen so austenitic grad you try to have high amount of nickel, and some of this austenite stabilizer.

And it is possible, if you have this chromium equiv valiant around here, the chromium equiv valiant, and nickel equiv valiant here from here on wards, so all these region, you know, you will have austenite stable at a room temperature. And is easy to check whether it is stainless steel austenitic or not, is to check will this be non magnetic gamma is alpha is ferro magnetic ferro magnetic, whereas this is non magnetic is para magnetic. so you will find it this is will be attract by magnet, but not austenitic steel. So, many place attains you know, you are one of the main application of austenitic steel is on this (( )) steel the when you why (( )) often you check that weather they are attracted by magnet.

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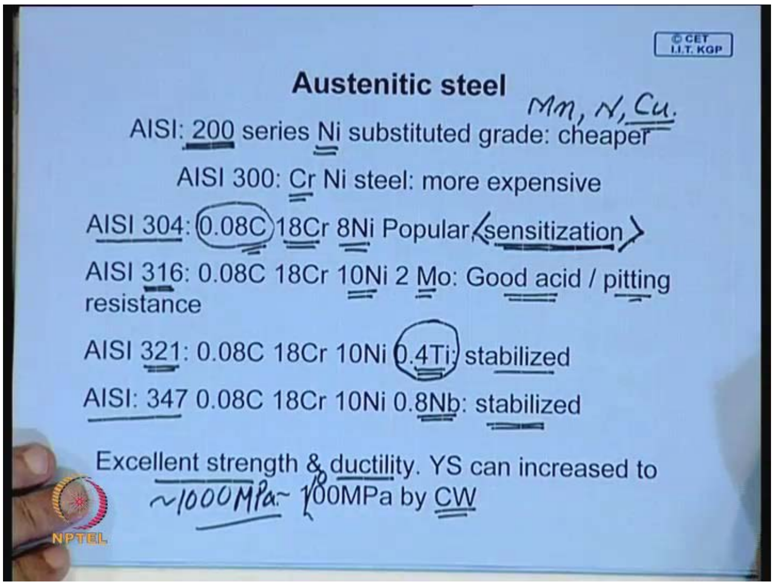

Now this, we talk about ferrittic, and martenstic grade of steel. Now, look at us austenitic grade of steels. Now, nickel is the very expansive alloy element, so there have been attain to have which austenitic grade which are cheaper, and they are nickel is substituted either completely or partially. And, common elements which are used to substitute primarily is manganese, and nitrogen, and copper, these are use to stabilize austenite to room temperature. But most common grades, these are AISI: 200 series is manganese substituted stainless; austenitic stainless steel ferrite and martinstic stainless steel also stainless the martinstic but austenitic steel definitely this are stainless all has high amount of chromium.

One of the popular grade, the most popular grade is AISI 304 you have 18 chromium, 8 nickel. But it does, and it has some carbon content, and we will see they effect of carbon and latter this responsible for problem a related to corrosion is called sensitization. So, under this condition, this does not is settable inter angular corrosion, and to avoid that of a certain alloy elements are added like molly it gives a better acid resistance or pitting resistance. You have little high amount of nickel to give acid resistance. So, this is another popular grade AISI 316, another is AISI 321, here this is called the stabilized will see later why stabilized add certain amount of very strong carbide former, and another popular AISI 347; this contains navobiyan is strong carbide format, this is also stabilized stainless steel.

Now, mean important property of austenitic steel; it has excellent corrosion, and oxidation resistance. It can use for high temperature application, and it has not only high strength, good ductility as well, the main problem is, it has mean ability heat treatment like martins tic heat treatment is not possible only way, it can be strength and cold work, and it strength can be increased to it should be 1000 up to around 1000 by cold work, by giving cold work, and increase the strength significantly.

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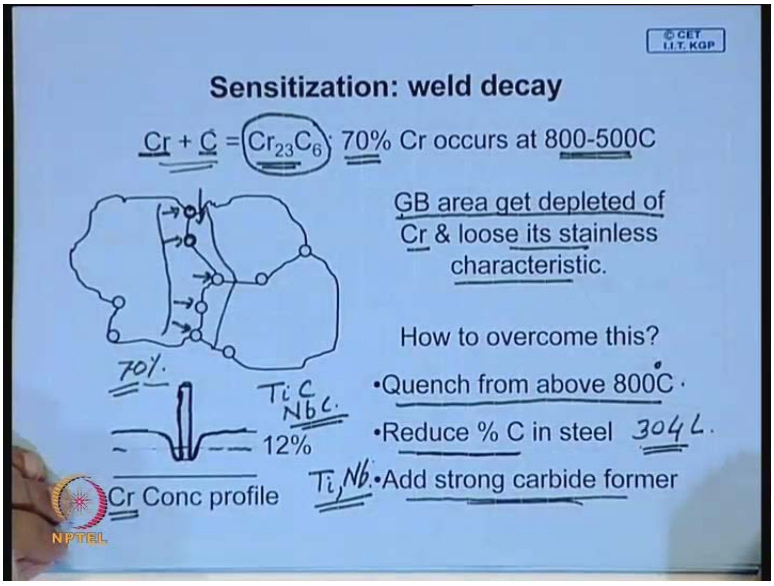

Now, let us; look us what is sensitization, we mention that oxidation or corrosion resistances of steel is derived from chromium, and this chromium which must be present, when it is present in solid solution; then only the steel has good corrosion resistance. No matter whether, it is austenitic or ferittic, this chromium must be present solid solution. Now, the problem it comes up can austenite can dissolve sufficient amount of carbon as well, and so what happen in this the austenitic stainless steel that carbon which is dissolve in austenite, and ferrite chromium, which also dissolve in austenite, that is possible they may be react to form carbide, and this happens heat by chance this steel is heated to be region, and which is often very common.

And if you try to why does the steel to make a vessel or something, you know some of the area will be heated to this region, and then type of precipitation will occur, and when the precipitation occurs, you know it consumes significant amount of chromium; around 70 percent chromium, you have a chromium carbide, then what happen if this chromium carbide forms at the grain boundary is a rounding region that chromium get depleted, all this chromium get depleted, and its comes here, so you a region which is depleted a chromium, and this users stainless corrosion resistance property. Therefore, this is where you know it is get attack by the environment, and it is susceptible to inter granular cracking.

And, this is the chromium concentration profile that we can think of, so this is the base chromium is twelve, and suddenly this comes down and near the precipitate is goes up to 70% and the question is and main reason for this is grain bounded area gets depleted of chromium, and lose its stainless characteristics. Therefore, grain boundary is susceptible to attack, and therefore, it is susceptible to inter granular cracking. And how to overcome this; one is if you quench from above 800 degree centigrade which is not always possible then do not get enough time for this reaction to take place, because about that most of that, this is soluble in the matrix which is often not possible, but if a material has been sensitize, if you can give this treatment then that problem will overcome.

Then other alternative way is the reduce carbon. So, there are certain grade like a three zero four a very low carbon; three zero four with a very low carbon. In that case, it is possible, that will not be susceptible to the sensitization problem. Another more common way of avoiding it; add strong carbide former like titanium or nayobiyam then what happens this reacts with carbon and then this formes titanium carbide or nayobiyam carbide and they stronger affinity for carbon then chromium, so therefore chromium does not enough, I mean carbon to react with it, and chromium is forced to remain in solid solution. So these are the very common way of avoiding that sensitization problem in steel.

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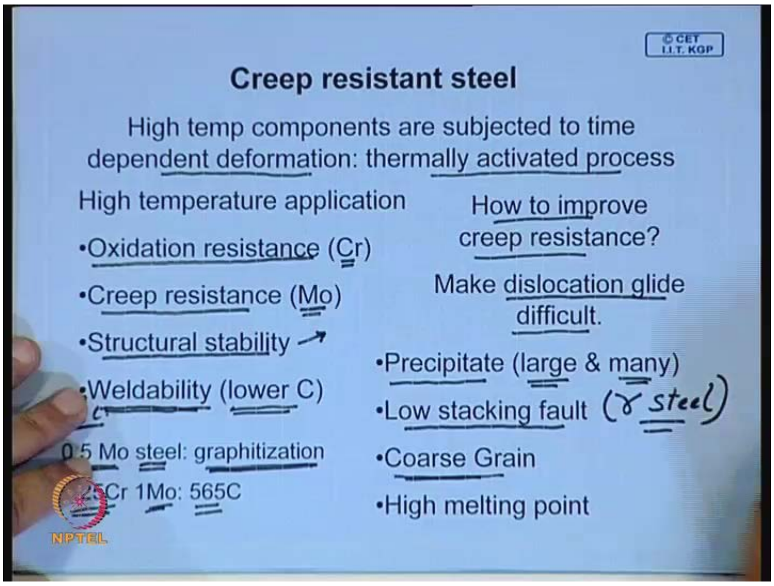

Now, quick look at creep resistance steel; now, we know, we talk about creep, which is time dependent deformation, any component which is used at a high temperature. In that case, there will be time dependent deformation, and this is a thermally activated process. Now, if you are therefore looking for is steel or any alloy which can withstand high temperature or high stress at high temperature. In that case, what you will look for; you look for the material must be able to withstand and that environment, that temperature it must a good oxidation resistance or it must have good creep resistance. Oxidation resistance common alloy element is chromium; creep resistance common alloy element is molly. Another is structural stability, which should have very stable structure, and it should have preferably some stable precipitate; and stable precipitates are coherent precipitate coherent or semi coherent precipitate is more stable.

So, look for such future in the alloy, and also it often, you know this creep resistance steel many cases, if it is if you are making the boiler, the super heater, you have to see that not only creep resistance, it must have good weld ability. Because main fabrication technique will be welding, and these tubes are welded, so often you know there is a limit that it will have lower carbon. Now, the earlier creep resistance steel, older power plant which does not operate at very high temperature may be the temperature is round 450 degree centigrade. So, there half molly steel is good for creep resistance, but this is known for a problem called graphitization prolonged use at high temperature, carbides gets convert it to graphite.

So, that is the major problem, so how to over this; this is over come by adding chromium and add a little bit of molly. So, two quarter chrome, one molly is a very common creep resistance steel. And this is used a 565 degree centigrade so mean is a question that comes up how to improve creep resistance, and it is a time dependent deformation, and deformation we know is a main reason is dislocation glide, if you make this is difficult, how do you make it difficult, you have precipitate large, and many precipitate you need to have to make this dislocation glide difficult. Sometimes you can make dislocation movement difficult by loading stacking fault energy like austenitic steel they have low staking fault energy. So therefore, two dislocations will be difficult movement will cannot crossly. Then another important factor is coarse grain and obviously, when you looking for creep resistance steel anything walking at high; you will definitely you looking for steel which has or material which has high melting point.

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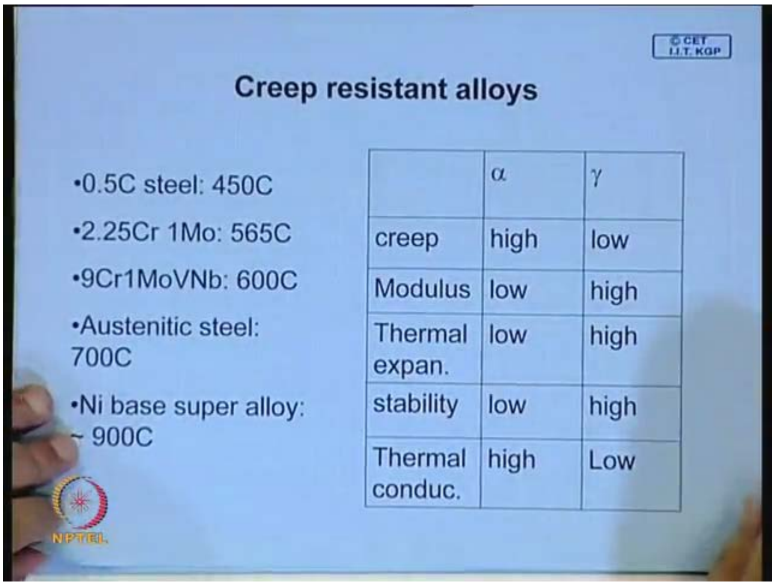

And these are the common creep resistant alloys, which are listed we talk about, and this is new grade steel currently used super critical power plant; it can go up to 600 degree centigrade, it has higher amount of chromium, and some amount of strong carbide formers, which gives stable carbides, and it forces molly to remain in solid solution to give it better creep resistance. Austenitic steels are good creep resistance, and higher temperature you go for nickel base super alloy. There is often a debate going on whether ferritic steel or austenitic steel a better for creep resistance alloy. So, no doubt at a higher temperature a space ability considered austenitic steel, you do not have alternative this has higher temperature capability. But ferritic steel, it is possible to improve its temperature capability to 650 degree centigrade. And because it has certain advantage like it has low thermal co efficient of expansion, then has higher thermal conductivity which are also quiet important. So, some of these properties which are comparison is given for ferritic and austenitic steel.

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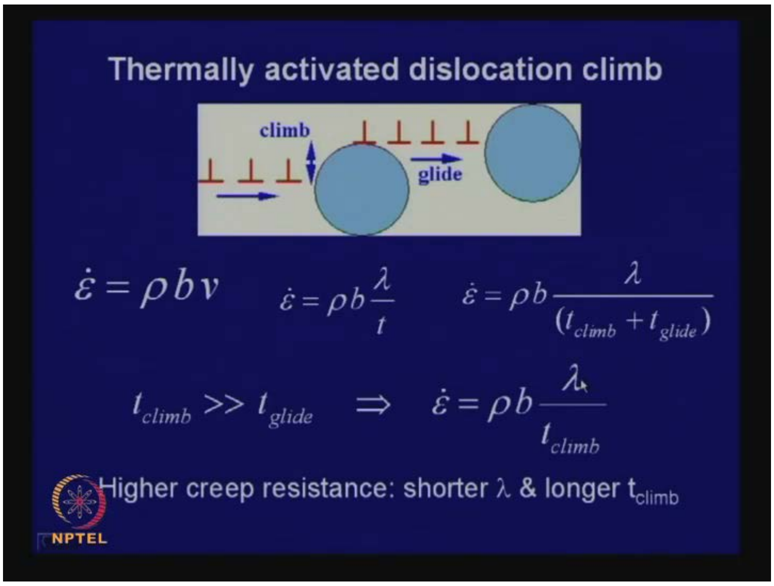

And this diagram is actually time to represent, and will quickly go to that. So, pictorial shown as how do you improve the creep resistance, so you have precipitates the lambda is the distance between the two, and the key reason is, so this is the creep rate equation this is dislocation density (( )) velocity. And, key thing you can assume that always time to claim is this total time; this time has to component, these are the layer arrange a dislocation pile which has formed which against a piratical. Now dislocation has to climb to overcome this, and this to make this closes very difficult, that means if you make this practical bega, it will take longer time to climb. And always t climb is much larger than the t glide. So, you can approximate the expression like this. So, what it means for the higher creep resistance, you have shorter inter particle spacing and larger piratical. So, that is the key.

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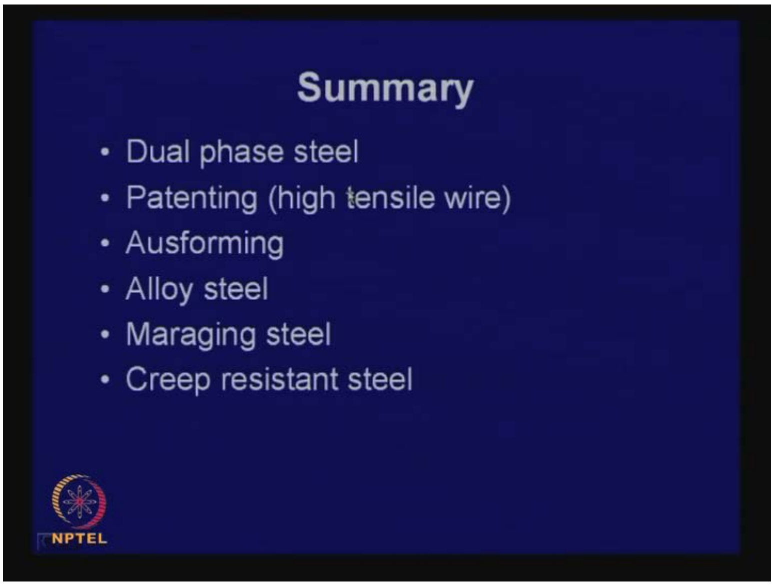

So, with this we stop here, and to some up whatever we have cover today is a dual phase steel, a special heat treatment call patenting, another heat treatment called ausforming, we talked about alloy steel; why it is necessary to add alloy element to steel, we talked about special grade of steel called maraging steel, and creep resistance steel. Thank you.