Welding of Advanced High Strength Steels for Automotive Applications
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Lecture - 03
Introduction to modern automotive steels

So, the conventional automotive steel's which are actually used in couple of decades earlier which are already you know;

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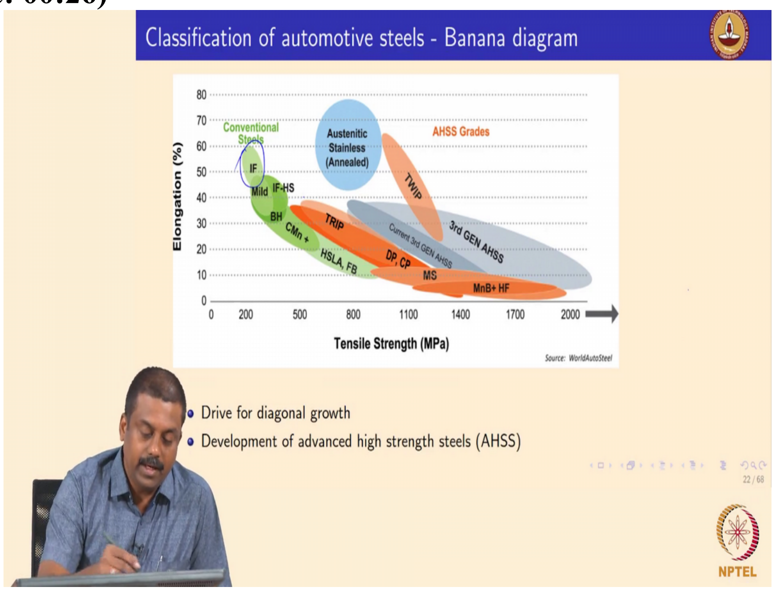

They were getting replaced with the advances high strength steels which we are looking at the last unit. So, now we look at the some of the introduction basic introduction about these conventional states. And we were looking at and say for example the IF steel's the IF-FHS the mild steel, the beckoning steel and common manganese HSLA and Ferric manganese steel. And if you recall my previous lecture the majority of the conventional steel's if you look at it know and they were all low-carbon steels which have excellent ductility.

If you look at it for example IF steel the percentage of elongation is about say 40 to 50%. and these things you know they were easy to produce as well as know because of the high elongation uniform elongation with very low stress to DRI yield these steel's were conventionally used in automotive industries in a large amount. If you look at the actual the microstructure they are very simple either ferritic micro structures or ferritic pearlitic micro structures.

Say for example the IF steel is known as an interstitial free steel, see these steel's, we possess excellent ductility so about 40 to 50% ductility. So, this is actually coming from the fact that you know the carbon concentration of these steel is extremely low within few ppm carbon concentration we had. The carbon atoms which are adding which are added in iron matrix generally you know they occupy the interstitial poisons in between the iron atoms.

But we add another some special align elements to pin the carbon atoms from the from interstitial presence. By adding say for example of vanadium or niobium, titanium to these steel's and these elements which are added vanadium, niobium, titanium and few ppm amount. And these vanadium, niobium, titanium they combine with the carbon atoms and form carbides of vanadium, niobium, titanium.

So, by forming carbides we deplete the iron matrix free of interstitial atoms. So, the in the carbon actually is taken out from the interstitial positions by these elements to form vanadium carbide, niobium carbide, titanium carbide because of these carbide formation we are now having an a pure ferric matrix. So, because of the pure ferritic micro structures and these steel have excellent ductility.

If you look at it in this banana diagram the IF steel has the maximum in from elongation about 40 to 50%. So, this steel it is really attractive in early say late 90s when they when the automotive industries they were trying to get steel's that can be easily formed during a; while making components for auto bodies. So, the IF steel's know that it is been used even now in some of the automotives of low load bearing members for example roof or door panels because we can easily form this team.

Again I mean the trend went on to know to identify the high strength steel's, so these automakers they wanted to know increase the strength of steel has been explaining an earlier slides. So, they started using a somewhat higher amount of elements such as vanadium titanium to form more carbides in the steel. So, that inner strength can be increased slightly higher than the convinced IF steels.

So, the area of high strength the interstitial free IF steel they pose a slightly higher amount of micro alloying reasons of niobium, vanadium, titanium to have precipitates volume fraction increased in the microstructure thereby providing its place in hardened. So, from IF steel the a of high-strength steel's were developed by adding a slightly higher amount of vanadium, niobium and titanium and this strength increased from say 200 to about 300 Pascal and they are about.

So, by increasing strength obviously the ductility elongation decreased slightly but still the IFHS is considered better than an IF because we gained a lot of strength improvement. And still the ductility is 42, 40% which is reasonable to use these steel's in place of the conventional interstitial free states. And the other type of the conventional steel which is which are commonly used in automotive application is a simple ferritic pearlitic mild steel.

So, these steals were like you know very simple alloying additions and also very easy to produce with the simple heat treatments because the microstructure is not that complex. So, the mild steel's so these were all classified into deep drawn and drawn deep drawn and X bar deep down grades DDD and EDD grades the containing the ferrite and then pearlite micro structures. The pearlite volume fractions again dictated by the common concentration.

As it is explained in the phase diagram based on the carbon concentration you may form some moment of protectoid ferrite and remaining I would be pearlite. So, the these grades they are also no providing you know excellent and the elongation as well as reasonable strength comparable to higher strength IF Steel there's strength varying from 200 to 250 ma Pascal and these steels where also no attractive automotive applications because of the excellent ductility they offer the; because of the excellent activity and uniform elongation.

And we can draw it and we can stretch it and we can make components from the deep drawn and the extra deep drawn grades. So, the other conventional steel before the area need the development of advanced high strength steels one of the steel's is Bake hardened steel's BH so this steel also contains very low carbon concentrations a carbon concentrations in a few 10's of ppm's the parts per million.

Unlike the IF steel the back hardened steel does not have a micro analysis so we deliberately leave carbon interstitial equations okay. So, carbon is actually present in the interstitial position for one very important reason. Again and the; this steel process contains very low carbon and the carbon atoms are kept in the interstitial poisons. So, why do we keep that in IF steel's we take it out and form micro lying precipitates whereas in bake hardened steel we keep the carbon atoms and interstitial equations.

And why do we keep it because these steel's if when you deform it okay so you anneal subsequently when you bake it in a pin baking cycle okay. So, you make a component you deform it whatever deep drawing or stretching and then you send the component after painting to baking cycle. So, we all know that you know the increasing in strength by the interstitial atoms by the interstitial carbon atoms when you have a driving force the carbon atoms go and segregate to dislocation friends okay.

So, these carbon atoms when they migrate during the slightly increasing temperature provided by the paint baking cycle the carbon atoms they go on and decorate the dislocations and thereby hindering the motion of dislocations in subsequent forming. So, in the beck hardening steel we leave the carbon atoms and deliberately in interstitial positions. So, these carbon atoms can migrate and then go and occupy the dislocation friends and forming a Cottrell atmosphere.

And this happens this migration of carbon atoms to the dislocation friend and it happens during paint baking cycles because you need some driving force for a carbon atoms to migrate and occupy dislocation friends. So, you have an interstitial carbon we begin with and you make component out of it and after you make the component by you deforming you apply paint and then components in 4-paint baking cycle.

And during the spring baking cycle when the carbon atoms migrate to the dislocation friend and once the component of decorate the dislocation a friend the subsequent deformation become difficult because the deformation is driven by the mobility of dislocations I then material gain some strength because you are providing new barrier for investigation motion. So, you can form it the material still have reasonably ductility about 30% elongation and you form the component but after forming and during paint baking cycle because of the migration of carbon atoms to dislocation friends.

And components against slightly higher strength then I mean without paint baking. So, this strength regaining and I can go up to say about 30 to 60 ma Pascal now which is and considered at the time and a very good because I the base material has materials containing the strength of 20 to 50 ma Pascal after paint baking cycle you gain about 30 to 60 ma pascal strength. So, it is useful especially near because all the automotive components are also painted and then baked.

So, we make we take the advantage of the carbon migration dislocation front to increase the strength and subsequently. So, these steel's like in IF, IFHS and beck hardening steels and mild steels and they were all considered now with the conventional steels because they are very simple and they provide very good formability. So, the automakers found it very useful because they can form the components within a with easy mill loads easy because of high elongation these materials can also be made into various components in not emotive parts.

But as I explained because of the increased the norms of the fuel efficiency as well as safety for performance the automakers they found that these things you know cannot meet the emission standards that were actually coming up in over the years. In order to meet those standards as I explained the automat auto parts should be and made into lighter and stronger. So, again you know if you want to make the auto parts a lighter and stronger.

We will have to go for high strength Steel's right. So, the options which are available for auto makers in late 90s for these steels which are actually in with increased amount of alloying elements for example carbon manganese and chromium and silicon added steel's and high strength, low alloy steels some extent frantic magnetic steels. So, these are all again the simple microstructure ferritic pearlitic containing steels with slightly higher amount of manganese chromium which can provide the substitution solid solution strengthening.

And because of these strengthening of this following elements this strength increase to higher the higher levels than the conventional the IF, IFHS and BS steels and because of the simple micro structures of a ferritic pearlitic or pearlitic bainitic the ductility decreased significantly. So, for example I; in a simple carbon manganese ferritic pearlitic steels the strength leveling event up to 500 to 600 ma pascal.

But with draft drop in my elongation compared to the IF steels so the formability became a big issue for these steel's. If you want to make an deep-drawn components or you know components requiring extensive deformation during processing these steels if they did not give enough ductility in during fall during farming operations. So, people wanted to invent a new micro structures which can give provide both strength and ductility.

So, the automaker's demanded the steels and also it was a significant ductility not as compared to know as good as the IF steel but reasonable ductility. But the strength levels would also be increased so that these teams the conventional steel's IF IFHS can be replaced with; even mild steel's can be replaced with high strength steels. But by doing so these steel's should also be able to formed into various parts, so, the driving force now for developing the advances high strength steel's is actually you know and they are coming from the fact that the high strength ferritic pearlitic steels do not have enough ductility.

And it is a given strength of HSL you would not gain any advantage in terms of manufacturability because of reduced elongation ductility. So, yeah then a lot of research went in to develop new micro structures with a nut with an objective of developing steel's which actually lies diagonally to this graph. So, we need to have reasonable strength as well as acceptable ductility okay.

So, in order to do that yes I will to explain the conveyance of ferritic pearlitic microstructure cannot meet the both the acceptable ductility and strength combinations. So, the steel makers they were already you know using various microstructure combinations to obtain the strength and ductility which is required to make the automotive components. The first development happened in this line is to develop micro structures containing two phases dual phase steel.

So, where the dual phase here denotes the ferrite and martensite microstructure okay. So, we form a microstructure containing a ferrite and martensite it is already explained martensite actually formed from the austenite in rapidly cooled to room temperature and by diffusionless manner displacive manner. And the martensite also provides a very high strength compared to the ferrite.

And during this process of martensite formation and there is also considerable increasing volume in terms of the expanding the crystal structure when the FCC transformed to body centered tetragonal and we can make use of the advantage of the properties of martensite in terms of mechanical properties and the volume expansion that actually happens when the matter state forms in in austenite or surrounding a ferrite matrix.

And subsequent slides we will see you know what I can tell this microscope is going to bring but as of now you can understand that the DP Steel's deal phase deals can have rate activity ranging from say 30% and the strength can be increased up to the tolerant to 49 ma Pascal. So, range of properties can be obtained by changing the morphology and the volume fraction of a ferrite and martensite mixture.

And we will see in detail the actual deformation mechanism and why deal phase steel can give you the elongation as good as the beckoning steel and strength which can go more than one Giga Pascal okay. And this became very attractive because now we have a material with very high strength and acceptable ductility and we can reduce the now thickness of the conventional steels to achieve the light reading.

And yeah by increasing strength you know we are not reducing these are forming or for mobility because deal phase steel can also give very good from forming formability. And apart from dual phase steel and then there are two other steel's which require yeah complex microstructure toward to achieve the strength and ductility combinations the ones actually strip steel. So, what is Trip steel? Trip here stands for transmission induced plasticity transformation induced plasticity I will come back to the the explanation of what is transmission in these plasticity in subsequent slides.

So, right now you can understand that the trip steel has a multi phase microstructure containing ferrite, bainite. So, I can say bainite and some amount of retained austenite okay. And yeah because of this special multi phase microstructure and trip steel again has excellent ductility as well as good amount of strength. So, do not obtain such a multi phase microstructure and we also need to have special heat treatments underlying elements.

But because of this multi phase micro structure especially the presence of retained austenite we can achieve a reasonably ductility and strength. So, the another steel in this class these complex phase the compressive extreme is similar to DNA steel and these 3 steals and DP, complex phase and trip steel they actually fall first generation advanced high strength steals. Because these steels they were the the first one to be commercialized.

And some out of Trip steel and deal phase feels very widely used number days in automobile bodies and the strength level they varied from close to 500 to 1000 ma Pascal. So, these tales know they started coming to commercial applications in early 2000 or so. And they provided much-needed you know like waiting possibilities because of the increasing strength distil process as well as the ductility which is needed to form the components of the Auto parts.

And if you look at the apart from these 3 Micra steels these diagrams also shows the various the the next generation steels for example the first and second generation is mainly a Trip, DP and CP with strengths up to 100 ma Pascal and we are actually moving from the first and second generation to achieve a diagonal growth. So, for example steel's with a modified DP dual phase steel, so we also have various quenching partitioning steel's as well as a trip steel.

Trip steel it is still not commercially used but this gives a great potential for a weight saving applications but there are some limitations in terms of alloying element. So, we are not going to really look at them because it is not really commercially applicable new trip stands for twin induced plasticity plasticity steels and apart from the steel switch process a very good strength and ductility.

So you also have one generation of steel which is now becoming very interesting for a commercial application is boron containing hot forming steel's again the hot forming steel's if you look at the compositions H of stands for hot forming Steel's in hot forming steel's the composition is similar to a ferritic pearlitic and the carbon manganese steels what you see over here. But the forming mechanism how you make parts out of these steel is different.

And slightly adding a small amount of boron and we can increase the hand ability significantly. So, you form the steel's for high temperatures and subsequently you cool it to room temperature during cooling process the entire micro structure becomes martensite. So, you begin with a ferritic pearlitic microstructure you take it to oscillation temperature and deform it at a status in temperature and the subsequently cool to room temperature.

During this cooling process after you make the components the components microstructure becomes completely martensitic. Thereby the strength of the component is in you know increase to close 1500 ma Pascal ETS. So, we will see in detail in subsequent slides the actual physical metallurgy of DL phase steels and Trip steel's and the hot forming steel's and how we can achieve that; this excellent combination of for micro structures which can give both strength and ductility.

As well as you know how we can achieve martensitic fully martensitic microstructure from ferretic paletic microstructure upon forming okay. So, apart from that if you look at it these great some of these steel's like the fully austenitic and unhealed steels is a very expensive in terms of alloying elements because in order form austentic, austentic like microstructure we may need to have to add nickel and chromium .

So, yeah so we are not going to really look at the in detail Arsenal steals again I said explain trip steals they are now they are in under development distilled also contains a high amount of manganese. In order to form between the microstructure and availability of this steel is still considered very poor if you use the conventional welding processes. So, we lost not be looking at these two steels. So, in we look at in subsequent classes the physical metallurgy of these first and second generation advances high strength steel's and the hot forming and complete martensitic steels which have very high strength upon forming.

So, in order to summarize this graph so the automakers and the steel makers they are going for diagonal growth of steel development where steel contains both high strength as well as acceptable ductility because of the light rating the conventional Steel's are all getting replaced with these advanced high strength steels in order to achieve better mileage as well as the cross performance driven by the increasing strength okay.

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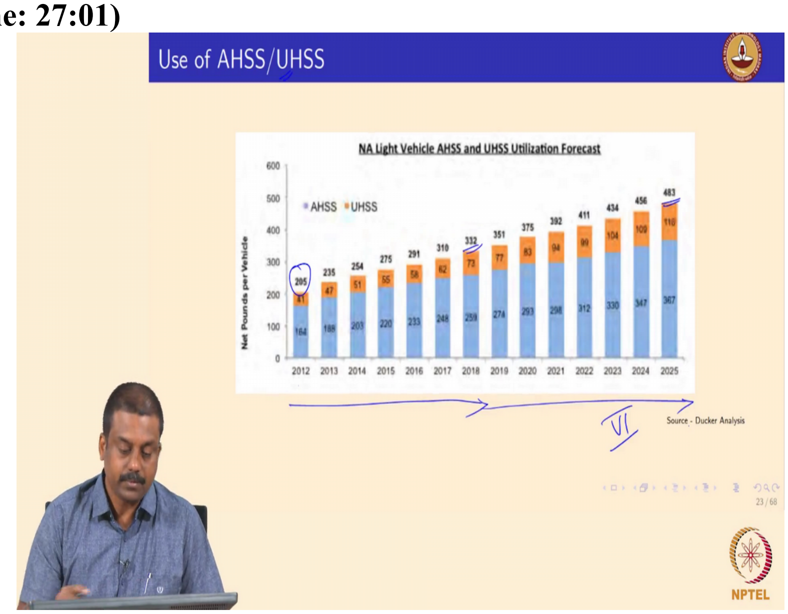

So, this graph shows the use of advanced high strength steel's and ultra high strength steel's again ultra high strength steels is nothing but an steel generally contains UTS of more than one Giga Pascal and this is the trend of usage of advanced high strength in auto bodies. So, this is in y axis we seen it pounds per vehicle and over the years if you look at and 2012 and the total amount of weight of steel that is actually advanced high strength steels used is about 205.

But it is actually in continuously increasing so I would say it is between 30 pounds and it is expected to go close to 480 pounds by 2025. In order to meet the emission norms which already showed in my previous slides too; for example if you want to meet Euro Bharath 6 norms and we have to reduce the weight of the car significantly. So, as I explained and unless the conventional mild Steel's are replaced with lightweight Steel's or any other alloys.

We cannot achieve the emission norms so therefore you more and more advance you see the advanced high strength steel is foreseen over the years. So, this is the forecast right now what what we are in so for compared to 2012 and it is going to go up because of the stringent emission norms is going to come over the years.

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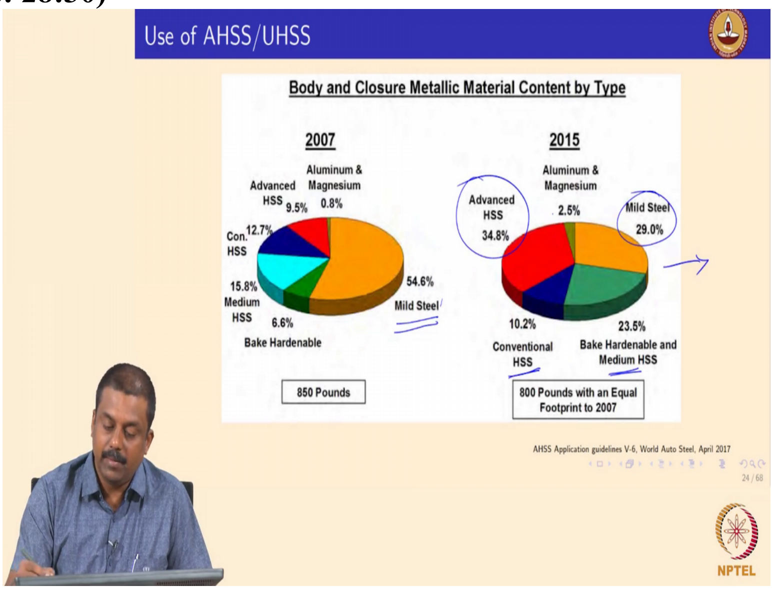

And this slide actually shows again the comparison between the various materials used in in auto two bodies so comparing 2007 and 2015 if you look at it as I actually explain the ferritic pearlitic steel's the mild steels occupied the majority of auto bodies about 55% as I showed so yeah so compared to 2017 if you look at 2015 the majority of mild steel's are replaced with advanced high strength steels mainly Arsenal phase and Trip or complex phase micro structures.

And as well as the conventional high strength Steel's which are carbon manganese austentic magnetic steels and some applications. So, you already see over 7 years or so in last decades the majority of mild steel's are already placed with advanced high strength steels the use of mild steels be significantly reduced and you still have for a low load bearing structures a bake hardnable and the interstitial free IF Steel's and Cecil free high strength steel's.

And if you see and the trend now is and these are advanced high strength steel's to keep on increasing the main beneficiary in terms of weight saving is the mild steels, the mild steels are all getting replaced with an advanced high strength steels.

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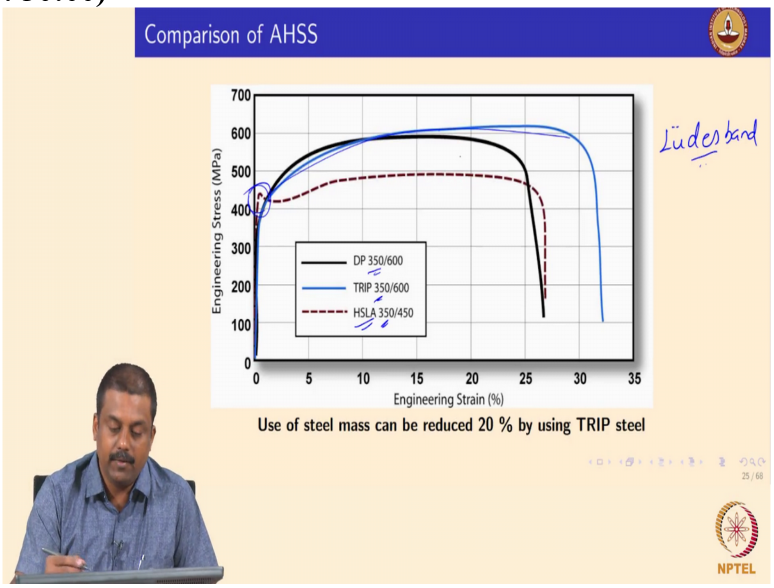

So, we will go in detail about the mechanical properties of micro structure of these steel's. So, why again the trip on DP Steel's of first generation they were very attractive in terms of mechanical properties is shown in this slide. So, this is a simple tensile testing result of HSLA and Trip and DP Steel's HSLA is high strength low light steel. So, if you look at Steel's all these three Trip and DP and HSLA the yield strength is similar right.

But if you look at the actual graph the for a given high strength the all these three threes for so decent of 350 ma Pascal but if you look at the curve of HSLA, Trip and DP even though all these 3 still have an equivalent yield stress the ultimate tensile strength of a deepen Trip is much higher than HSLA steels apart from the increasing the ultimate strain shear strength and the trip NTP also gives excellent uniform elongation okay.

You see that the elongation percentage increased significantly as well as the other important point over here in the HSLA steel they so ill point phenomena right. So, so this is considered, not acceptable or it is not a considered beneficial especially the material least formed deep-drawn are stretched to make auto components. Because you will end up forming what you call a Ludes band it is a Ludes band formation significantly affect the surface appearance of the component that are stretched or that are formed.

So, apart from the advantage of increased uniform elongation the DP and Trip steel they also give deformation without the point phenomena okay. So, so so the advantages in terms of increasing strength in UTS ultimate tensile strength as well as the total uniform elongation it is increased significantly. The DPN Trips were considered very attractive to replace the conventional high strength and conventional ferritic pearlitic steels okay.

So, we like to summarize here so we looked at the various modern advanced high strength steel's how these Steel's were found to be no attractive compared to the conventionally used ferritic pearlitic or a simple pearlitic based steels and we also looked at the steels that are getting developed for example trip steel or austenitic stainless steels. And the way we need to have a diagonal growth in elongation and in terms of elongation as well as the strength in the material.

And we also looked at the trend in the usage of commercial applications of; usage and commercial application of advanced high strength steels over the years. So, it is going to go increase because to meet the emission norms. So, the conventional use mild states are all replaced with the advanced high strength steels so about 55% of mild steel's which are used in late 90s are all replaced with advanced high strength steels.

And yeah we are going to go even further and the properties of Trip and DP Steel's and they are superior to the HSLA steel in terms of uniform elongation as well as the increasing yield stress; ultimate tensile stress for any given yield stress and apart from the strength and the elongation advantage and DP and Trip steel they also do not so yield point phenomena so, the surface appearance and so of the component that are formed and they are also better than the HSLA steels.