Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-31
Surface Modification Techniques: Carburizing I

Hello I welcome you all in this presentation related with the subject fundamentals of surface engineering, in the previous presentation we have talked about the principle of surface modification by changing the chemical composition of the surface and near surface layers. So that the required change in the microstructure and mechanical properties can be achieved for improving the wear resistance. Now we will be talking about the different methods which are used for changing the surface chemistry for surface modification,

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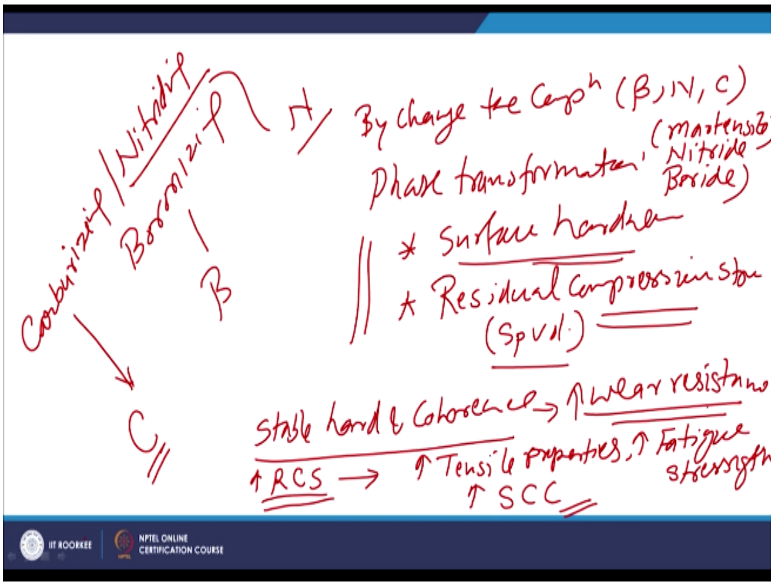

Carburizing / Nitriding / Boronizing

C // B

H / By change the Compⁿ (B, N, C)

Phase transformation (martensite – Nitride – Boride)

* Surface hardness

* Residual compressive stress (Sp vol.)

Stable hard & coherence → ↑ wear resistance

↑ RCS → ↑ Tensile properties, ↑ Fatigue strength

↑ SCC

So that the required improvement in wear resistance can be achieved. So the main methods which are there for surface modification by changing the surface chemistry includes carburizing, nitriding, boronizing and in these methods basically in carburizing carbon content at the surface layer is increased, in nitriding nitrogen concentration is increased, well in case of boronizing boron content near-surface layers is improved.

And in these method basically some of by changing the surface layer composition using boron, nitrogen or carbon which I too get few phases or phase transformations which will increase the surface hardness through the phase transformations. As well as it will also lead it will with this kind of the changes in form of the phase transformation will be leading to the development of the residual compressive stresses at the surface.

So the phase transformations primarily which take place after the chemical composition modification is like martensitic transformation or martensite formation of nitrides of iron and other compounds are elements if they are there and borides iron borides. So these phases are hard and these are formed with the change of specific volume. So because of their high hardness the surface hardness of the component which is modified for property investment is increased.

And the transformations which are occurring with the increase of specific volume due to formation of these phrases results in the residual compressive stress formation at the surfaces and whenever these favourable changes are achieved at the surface we get the very stable hard and coherence surface and these factors in combination increase the wear resistance of the material.

On the other hand development of the residual compressive stresses also increases the tensile strength or tensile properties for increases the fatigue resistance because the severity of the external tensile stresses is reduced. So the fatigue strength or fatigue resistance is increased, at the same time stress corrosion cracking which occurs in presence of tensile stresses. Since the reduction in the tensile stress is being applied externally in presence of the residual compressive stresses leads to the improvement in the compressive stress corrosion cracking tendency.

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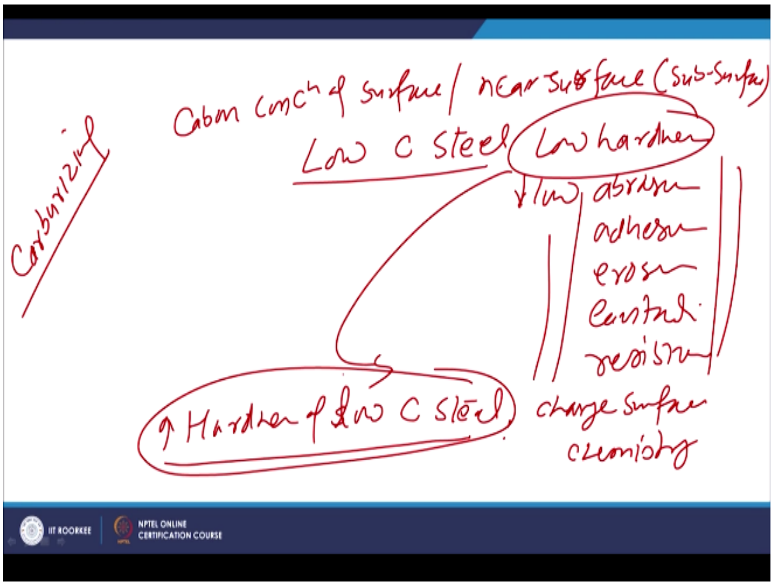

Carburizing

Carbon conc^n of surface / near surface (sub-surface)

Low C steel

Low hardness

↓ low abrasion

adhesion

erosion

cavitation

resistance

↑ Hardness of low C steel

change surface chemistry

So the carburizing nitriding and boronizing are favourable not only from the wear resistance point of view but they also help in enhancing the mechanical properties of the component. So if we have to modify the surface composition then what kind of the metal systems are chosen for this purpose. So will be taking a first of all carburizing process. In this process basically carbon concentration of surface and near surface layers up to the required depth near surface layers or near surface which we say also as a subsurface layer.

This one is increased, so of which steel is basically the low carbon steel components which have the low this components which offer the low hardness and therefore very low abrasive, adhesive, erosive and cavitation resistance and therefore if we want to improve the resistance of low carbon steels to these conditions of the wear then it is required that it has slightly better hardness.

So for increasing the hardness of low carbon steel although there are various methods like we may perform the control surface layer deformation. But it will be this increase will be up to the limited extent. So in order to have very controlled and significant increase in the hardness of the low carbon steel 1 very good method is that changing surface chemistry or surface composition of the low carbon steel.

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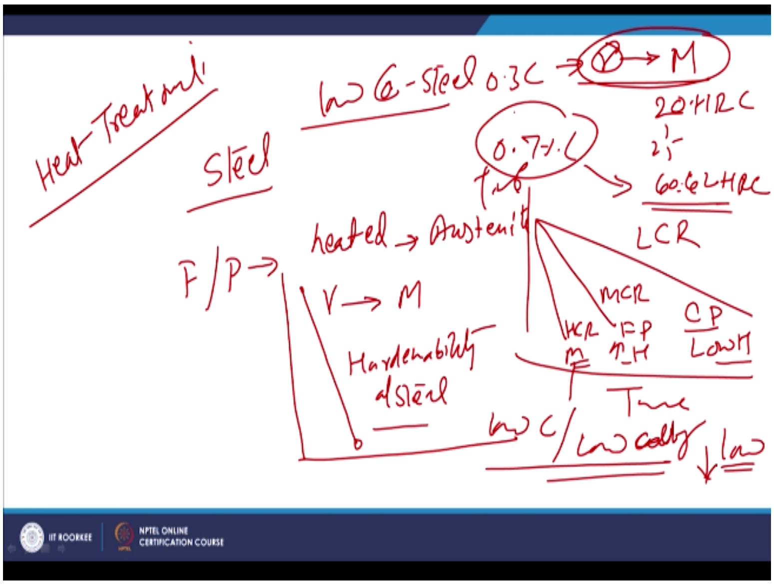

And why this change is needed for increasing the surface hardness of the low carbon steel that is what will try to understand, we know that heat treatment of steels respond to the heat treatment very nicely. Because whenever steel like say the plain carbon steel having the ferrite and the pearlite under the room temperature conditions whenever it is heated it forms the unstable phase like austenite.

And austenite on cooling at different rates results in the formation of a different phases like if this is a low cooling rate it will be resulting the course pearlite and the low hardness. On the other hand if we use slightly higher cooling rate like this is a scale of time and temperature on the y-axis so somewhat medium cooling rate will be leading to the fine grained pearlite it will be leading to the somewhat better hardness.

And significant increase in hardness is achieved through the using the high cooling rate we get the high cooling rate, we get the martensite transformation and this increases the hardness a significantly. So due to the martensitic transformation the increase in hardness is significant but high cooling rate from the austenitic state to the low temperature cannot be achieved in case of all types of the steel.

Because the transformation from austenite to martensite is primarily determined by the hardenability of the steel. So steels having the low carbon content and the low alloy content, low alloy concentration the hardenability is very limited. So in order to increase the hardenability efforts are made for increasing the carbon content and if they have the alloying element then certainly the increase in carbon content will be beneficial.

There is a direct relationship between the carbon content present in the steel and the kind of hardness that we get after the martensitic transformation, sometimes like the low carbon steel having 0.3% carbon subjected to the transformation by the rapid cooling from austenite to the martensite. We get the hardness like say that 20 HRC, 20 to 25 HRC. On the other hand if the same kind of the transformation is realised.

In case of the steel having the 0.7% carbon then this increase can go as high as 60 to 62 HRC, so this significant increase in hardness can be realised through the austenite using the austenite to martensite transformation by rapid cooling only if the carbon content in the steel is high.

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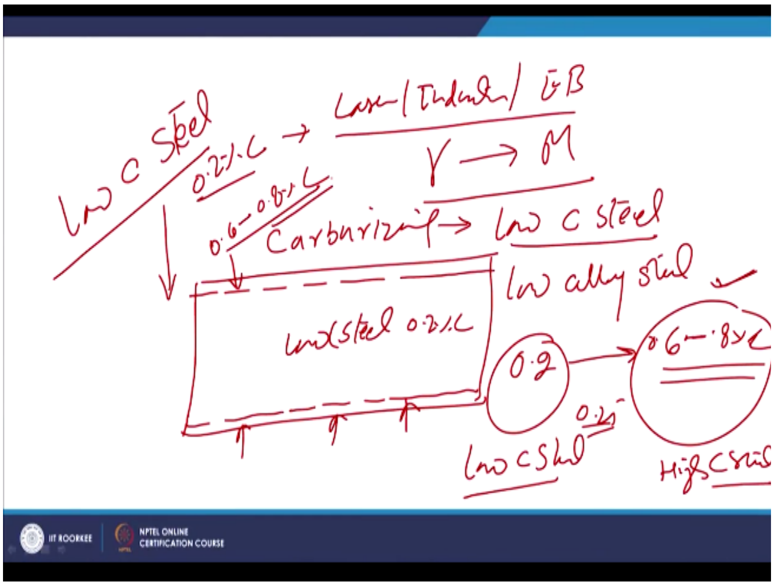

So if so just by the rapid cooling by heating the low carbon steel followed by rapid cooling we cannot achieve much increase in the hardness. So the low carbon steels having likes 0.2% carbon if for increasing the hardness or for case hardening like a shallow hardening methods if they are applied in for using the laser using induction or using the electron beam methods, then we cannot achieve much increase in hardness despite of the austenite to martensite transformation which were we all the very limited.

So since in the increase in hardness even due to this kind of transformation is limited. Therefore it is required that the carbon content of the surface layers in the steel is increased and therefore we use the method of the carburizing, in carburizing primary carburizing method therefore is primarily used on the low carbon steels or the low alloy steels having very limited carbon content. So this increase so using the carburizing will be increasing the carbon content save from 0.2 to 0.62.8% range.

This is a range of the carbon content in which it is increased from very low level to the higher level. So this is basically falling in category of the high carbon steel while this is the low carbon steel category where carbon content is less than 0.25 and if the carbon content is more than 0.5 then it will be the high carbon steel. So increase in carbon content of the surface layers or to likes a in the code.

This is a component of the low carbon steel having the 0.2% carbon near-surface layers of the carbon and near surface layers of the components are subjected to the carburizing with the increase of carbon content up to 0.6 to 0.8 %. So are the primary purpose of carburizing is to increase the carbon content at the surface or near surface layers. So that subsequent heat treatment can result in the required austenite to martensite transformation with the significant increase in hardness.

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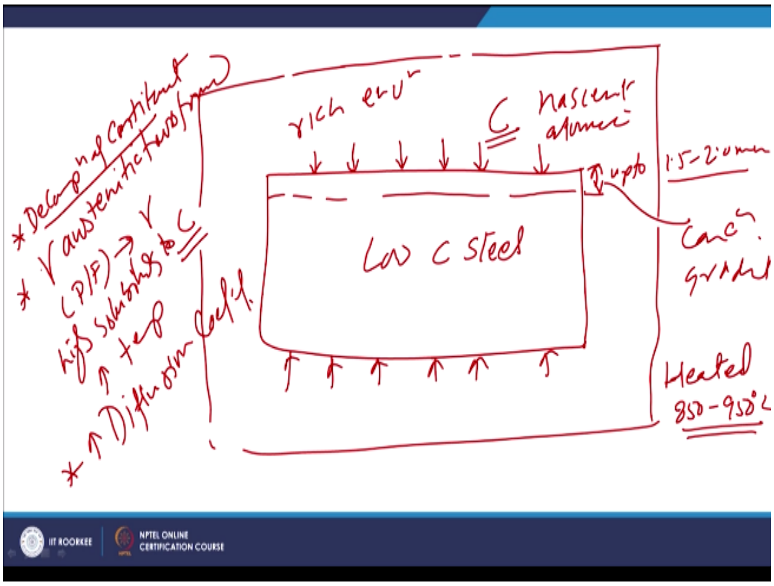

So now we will see the kind of the conditions which are normally used for carburizing purpose, for carburizing like say this is the component which is to be carburized of the low carbon steel. So it will be exposed to the suitable environment where the carbon is present in form of the atomic states. So carbon in very innocent atomic state is made available. So carbon rich environment is created around the component.

This is one aspect and the second and third component is the entire in component is required to be heated to the temperature high enough. So this temperature may be in the range of 850 to 950 degree centigrade. So heating of the component in the carbon rich environment at high temperature leads to the active diffusion of the atomic carbon from the surface to the subsurface layers of the component.

And this happens due to the concentration gradient of the carbon from the environment to the components of the high temperature facilitates 2, 3 aspects, 1 is high temperature will ensure the thermal decomposition of the consequence which are providing the carbon nascent or atomic state like CO2 formation or the other chemical reactions which will be facilitating the availability of the nascent or atomic carbon in all around the component which is to be carburized.

The second thing is the heating of the component to the 800 to that from 800 to 950 degree centigrade temperature in this high temperature facilitates austenitic transformation low carbon steel gets transformed into the austenitic state because initially in the room temperature it is pearlite and ferrite and pearlite which gets transferred into the austenite on heating is this temperature.

So formation of this austenite which is having the high solubility to the carbon and the solubility to the carbon in the austenite also increases with the temperature. So these are the 2 functions which are realised by hitting the component at high temperature 1 is thermal decomposition of the constituent usually provided in the nascent carbon in the atomic state and the second one is the transformation of the ferrite and pearlite having the limited solubility to the carbon in solid state.

And transforming these phases into the austenite, austenite is having the highest solubility to the carbon as well as the increase in temperature also increases solubility of carbon in the austenitic states. This is third purpose which is realised by the heating the component to the high temperature that is increased of the diffusion of the carbon into the substrate or the component diffusion coefficient of the carbon steel service state is increased.

Since the carbon has to defuse from the surface to the subsurface layers up to the required depth which may be like say up to 1.5 to 2 mm depth. So obviously this is the carbon is getting diffused in the subsurface a surface and subsurface layers of the steel. So there will be concentration gradient as well. So in this depth that there will always be concentration gradient.

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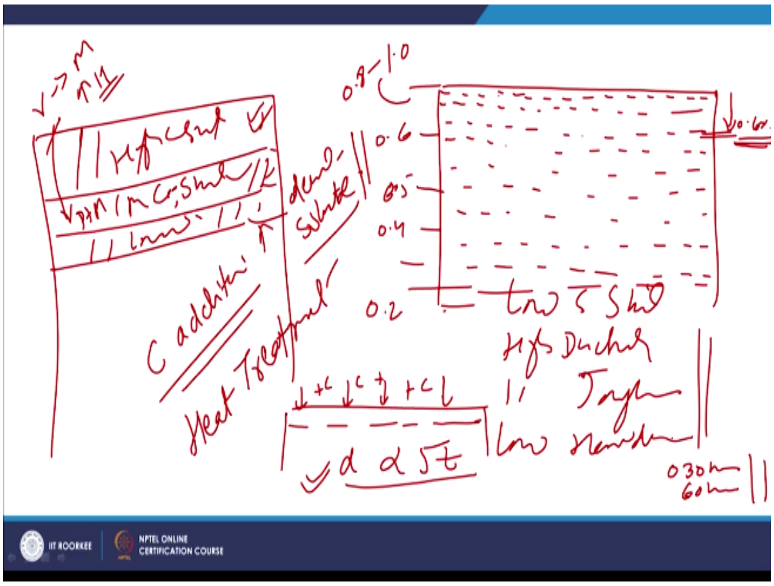

And concentration will always be higher at the surface and include increasing in the sub surface region. So if we try to understand the concentration gradient it will be too high at the surface and then it will be somewhat lesser as we go deeper like this. So the concentration of the carbon in the subsurface region will be decreasing and accordingly it will be leading to the, so here will have the low carbon steel substrate which will have the high ductility, high toughness and low hardness.

So these are the typical properties of the low carbon steel on the other hand near the surface layers we may have like 0.8 to 1 % carbon while in the subsurface region it will be gradually decreasing like 0.6% here, 0.5% here 0.4% here and gradually it will be reaching to the 0.25% as per the carbon concentration in the substrate. So if and once after the carburizing the carbon content has been invest in the steel components.

Simple the carbon edition will not help in achieving the required hardness, carbon edition simply will be present as an element or as a solute. So the presence of carbon is a solute in the iron is not going to help much and therefore it is important that after carburizing suitable quenching or hardening heat treatment is carried out. So since the now you see the situation is like this where in they are 3 layers.

This is of the high carbon steel, medium carbon steel and low carbon steel as far as the increasing depth from the surface is concerned. So when the heat treatment is performed surface and surface layers will be acting as a high carbon steel carbon content is more while the surface is which are further deeper they will be behaving like a medium carbon steel and the core will be acting still acting as a low carbon steel.

So accordingly will be able to see the martensitic transformation since the carbon content is more so on the austenite to the martensitic transformation will be getting the highest hardness will be here in this top layer band and thereafter basically second band where the carbon content is slightly less, here we may have pearlite+ martensite and martensite also of the somewhat lower.

So then this zone will be slightly softer and further softer zone will be there in the subsurface region, in light of this if it try to plot the variation in the hardness as hardness residual stresses and the carbon content as a function of the increasing sub surface from the surface then there will be a continuous gradient that is 1 aspect. Now how deep the carbon will be enriched during the carburizing process that will be the function of the time for how long component is exposed in the carbon rich environment.

Say this the carbon rich environment is present components of carbon will be getting diffuse in the subsurface region, since the diffusion is a time based phenomena it will take time to get the carbon will take time to diffuse into the component. So the depth up to which carbon will be enriched that will be the function of the time. So that case depth or the carburizing depth D is found proportional to the square root of the time.

Longer is the time required for increasing the depth which is carburized and once the depth up to the required depth we have carburized carburizing had been done for required hardening of the surface and surface and subsurface layers or this carburizing will be stop like say if I know that the carbon content minimum carbon content to achieve the required hardness is 0.6.

This is the 0.6 is the percentage of carbon required to achieve the required hardness, so how much time it will take to enrich the carbon content in the subsurface layers of 2.6 that we have to identify based on the rate at which carbon is getting diffused into the surface or subsurface layers. So this time may vary as for the temperature and the steel composition but normally it may be like 30 minutes to the 60 minutes.

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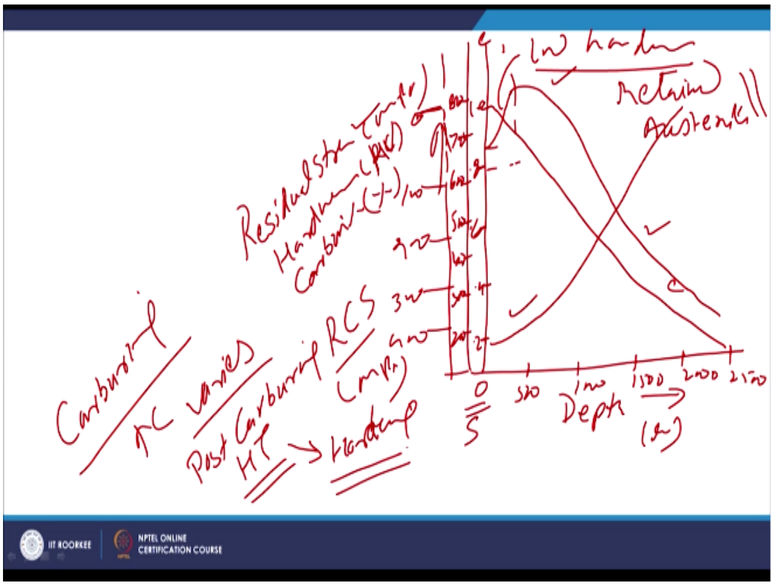

That is the normal time it takes to defuse the carbon in the subsurface layers. So the depth carburized depth is found directly proportional to the proportional to the square root of that time of the carburizing. Now I will plot 1 double plot which will be showing the variation in the residual stresses then hardness and carbon percentage. So all in the y axis all will be shown in one go.

So increasing depth like say up to 500 micrometre, 1000 micrometre, 1500 micrometre, 2000 micrometre and 2500 micrometer, it is if 05, 1.5, 2, 2.5 m, so depth in micrometres and in the y-axis we have residual stresses in MPA and then the hardness in the RC in terms of HP and the carbon content with percentage. So in the y axis if we have like say we can draw the three different lines corresponding to the like this.

So that the inner one is for the carbon content 0.2, 0.4, 0.6, 0.8, 1.0, this is what the carbon content, so the carbon content increases directly, so it is too high at the surface and then it will be decreasing below the surface. This is the kind of variation in the carbon content at the surface. So this is about increasing from the surface this is the surface and carbon content maybe as up to 1%.

As we go down with the surface will keep on decreasing, now if we try to plot the variation in hardness, so the hardness variation like 100, 200, 300, 400, 500, 600, 700 like this, so will start 200, 300, 400, 500, 600, 700, 800. So the hardness what we find at the surface layer where carbon is too high we find the carbonate hardness is somewhat lower and then it is maximum is slightly below the surface and then it will be decreasing like this.

So the hardness variation goes in with that in line with the carbon content but at the surface where carbon is too high we find the lower hardness and this low hardness is activated to the formation of the retained austenite, I will elaborate this subsequently but at the surface layer the carbon content is too high it leads to the formation of the retained austenite.

While other surface layer is well the carbon content is somewhat lower like say here in this range it is like a 0.8 at the surface where it is too high the formation of the retained austenite hardness which is in the lower hardness, then will be plotting the variation in the residual stresses, so residual stresses like say this is 0, 100, 200, 300, 400, so residual stresses these are the compressive residual stress RCS in MPA.

So residual stresses are compressive and they will be decreasing in magnitude like this as we go deeper. So resistance becomes 0 at the surface and becomes 0 as we go down to the core and residences are maximum compressive at the surface. So this the surface as a magnitude is like 300 to 400, 400 to 500 MPA as per the yield strength of the materials. So this is what it shows are now.

So what it suggest that when carburizing is done it leads to the increasing carbon content but carbon content varies from the surface and this kind of variation in the carbon content in the at the surface after the carburizing leads to the variation in the carbon content variation in the hardness, variation in the residual stress but for realising these hardness we need to perform the host carburizing heat treatment.

So this heat treatment is basically the hardening heat treatment, so what kind of heat treatment cycle is not be used and how does it leads to the formation of the required properties in terms of the hardness and compressive stresses that is what will discuss in the next presentation. I will conclude this presentation, in this presentation basically have talked about the underlying principle of the carburizing and the how what are the metal systems where carburizing can be used effectively and when the carburizing is performed how does it affect the properties of the steel components, thank you for your attention.