Joining Technologies of Commercial Importance

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Lecture - 32
Fundamentals of Weldability of Metals

Hello, I welcome you all in this presentation. This presentation is based on the topic weldability of the carbon and the alloy steels. And this one is related with the subject joining technologies for the metals.

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So, the topic is weldability of carbon and alloy steels. So, first we will try to understand the weldability word and thereafter we will go for the carbon and alloy steels and how the weldability is effected by weldability of the carbon steel and alloy steel is affected by the various parameters related with these steels. So, weldability as it reflects ability to get welded or we can say ease of welding.

But this ease of welding is defined under certain conditions like ease of welding by a give process for a give purpose means the joint should satisfy the requirement of the purpose, requirement or the purpose for which it is being made under given set of the conditions and the joint is made under a purpose and the weld is made, a joint is made under given set of the fabrication conditions.

There are three things which are important that a metal when welded by a given process for a given purpose under given set of the fabrication conditions then with which ease it can be welded or ease with which it can be welded by a given process for a given purpose under a given set of fabrication conditions that will determine the ease of or you can say that will determine the weldability of the metal which is ease of welding.

It is determined and all this is all determined by you can say quality of weld which is produced like the metal system when joined by a given process at the given set of the conditions like this. So, what kind of the quality of the weld joint is obtained? How much effort is required for producing weld joint and third the economic aspect or the cost of producing per unit joint. So, in general if the efforts required for producing the given weld joint and the cost for producing the given weld joints increase.

Then the weldability of the metal system in general decrease at the same time if when the joint is made by a given process for a given purpose and the given set of the fabrication conditions then what kind of –what quality of the weld is made that also determines the weldability or the ease of welding if under given set of the conditions of the welding like process purpose and the fabrication conditions.

If the quality is poor, then we will say the weldability is poor or weldability is good. So, as far as the process is concerned so if we see the weldability is being influenced by the process it is the given welding process, the purpose and the fabrication conditions. So, these are the important things. So, like say metal, metallic components to be joined by the welding so process is one thing.

Procedure of welding is another. Purpose is third and fabrication condition is forth. So, if you see here the process the given metal A, say A metal is to be joined two parts of the metal A to be joined using a given process. So, the process may be our gas metal arc welding. It may be GTAW gas tungsten arc welding, SMAW, silicon metal arc welding, SAW submerged arc welding, the plasma arc welding, laser welding etcetera.

There may be number of processes and when a metal is welded by a particular process for example when say this is simple carbon steel welded using the GTAW process the quality is excellent because the damage to the base metal is minimum weld size is minimum and the soundness of the weld joint is extremely good so it results in very good quality weld joint. But the process productivity is slow.

So if we will see from the quality point of view its weldability is extremely good but if you see the productivity point of view the productivity of GTAW process is very low. Under the same conditions if it is welded like say there is another example like if aluminium is welded using the Shielded metal arc welding process then the quality is extremely poor because aluminium reacts with the atmospheric gases.

And it results in the very poor quality weld joints so even it may be weldable also. But if the same is welded using the GTAW process then we may find that the joint is extremely good because the inert gases associated with the GTAW process offers very good products the aluminium from the atmospheric gases and results in the good quality weld joints. So, same metal welded using the two different processes can result in a different quality of the weld joints.

And that in turn can affect the ease of welding or the kind of efforts that are required for developing the weld joint. The quality of weld which is made so this is how the process affects the ease of welding for a given metal.

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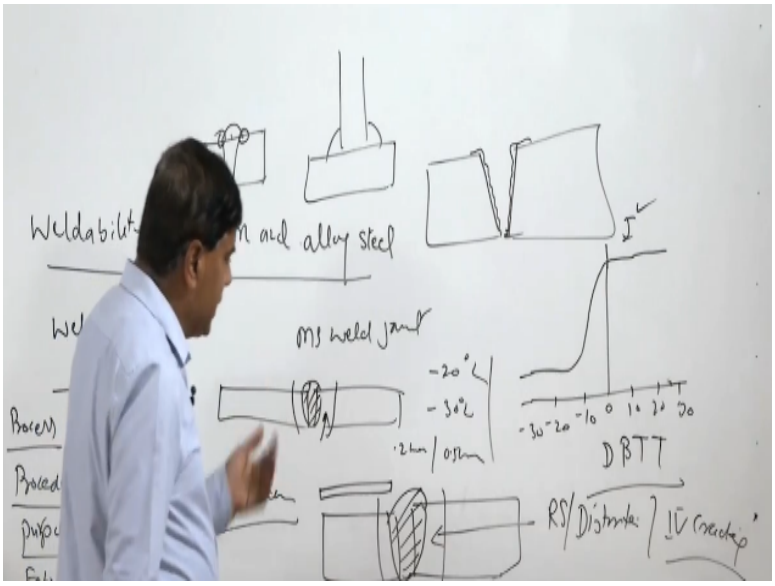

Similarly, the procedure involves the like say the kind of pre heat being used preparation of the base metal like may be edge preparation or cleaning of the faying surfaces then the process parameters, welding process parameters, post weld treatments. So, these are the different steps related with procedure like how much preheat is being used. If say material is very of the high hardenability so if the proper preheat is used, then it will result in a good quality weld joint.

If the preheat is not proper or it is less than the required one, then it can lead to the development of the cracks or development of the higher residual stresses which can degrade the performance of the weld joints so proper preheat has to there. The proper kind of the edges must be prepared otherwise the joints may be complete like if very thick plates are to be welded then square group geometry may not work in that case we may require that the edges are prepared properly.

Like say we V grove, U groove or the single V, single U, J as per the requirement different kind of groove geometry will be required proper preparation. The faying surfaces or the base metal surfaces must be clean properly from the presence of impurities. They must be removed in order to avoid the presence of unnecessary gases in the weld metal or the presence of inclusions. So, if it is not done then even despite of all best efforts we may not get the good quality weld joint.

Similarly, in selection of proper process parameters also effects the ease of the welding if two high heat input is used then it will degrade the heat affected zone, it will result in the undercut, it

may lead to the lot of thermal damage to the work piece, lot of residual stresses and distortion tendencies will be associated with PWHT or post weld heat treatment. So, post weld treatment involves like chipping of the slag or the relieving the residual stresses.

Or the heat treatment for annealing, normalizing etcetera as per the requirement. So, if these are not followed properly then it may result in the joint something then what we need. And that in turn may degrade the quality of the weld joint or it may improve the quality of weld joint as per kind of the procedural steps are being followed. So, proper procedure is to be followed for developing good quality weld joint.

If these are not used then we will see that the quality of joint is not up to the mark or it is full of the issues like poor soundness of the weld metal or unnecessary excessive residual stresses and distortion tendency, wider heat affected zone etcetera. Similarly, the purpose for which the joint is made. The joint may perform very good under normal conditions like if we take any simple mild steel, the mild steel weld joint may perform excellently very good under the normal ambient conditions.

But even the same is used under the minus say 20 or -30 degree centigrade under subzero conditions then we find that joint loses it performance under the impact conditions very badly and that happens due to the loss of the toughness under the subzero conditions which is represented by the typical curve which is called ductile to brittle transition temperature. So here we have say 0 degree centigrade -10, -20, -30 degree centigrade.

And her plus 10, 20, 30 and the weld joint impact toughness if tested then we may see that at the room temperature or above 0 degree centigrade it is very good but as soon as we reach to the below 0 degree centigrade we find that there is a drastic reduction in toughness of the weld joint. So, this y axis shows the impact energy in Joule. You see Charpy V-notch impact toughness of the material decreases or the weld joint decreases very rapidly under the subzero condition.

So, as far as purpose is concerned MS weld joint performs very good under the normal ambient conditions, weldability is good. But if the same weld is used under the subzero conditions then

the joint will not perform and it will fail prematurely. So, it will not be good for the weld joints. Similarly, the temperature conditions then load condition under the static condition joint performs excellently.

But some of the joints perform very poorly under the dynamic load conditions like the impact and the fatigue. So specially the joints with the fillet welds perform very poorly or joints having the highest concentration at the toe of the weld. They also perform very poorly under the fatigue load conditions. So, fatigue loading degrades the performance of the weld joint because they invariably have the stress results in form of the weld discontinuities.

Or the high stress concentration at the toe of the weld. So, the purpose like that kind of loading conditions, loading conditions, temperature conditions and environmental conditions which may be dry or which may be corrosive. Since, the heat effect zone of the weld joint experiences the changes metallurgical also sometimes unfavorable transformation in the heat affected zone degrades the corrosion performance.

So sometime the weld joint corrosion resistance is degraded and so if the weld joint which is properly sound, good mechanical properties but when it is used under the corrosive conditions it does not perform good and that in turn leads to the reduced weldability from the corrosion resistance point of the view of the weld joint and similarly the fabrication conditions are also important like what thickness is to be welded.

Sometimes metals very easily weldable of 5 mm or 10 mm thickness but if the same is welded for very thin sheet like say 0.2 mm 0.5 mm sheet is welded it is found very difficult to weld and produce the sound weld joint of such a small thickness. Similarly, when we work with a very heavy thick plate like 40 mm, 50 mm, 60 mm then these pose lot of problems associated with the heat affected zone due to the multi pass welding.

What we see that heat affected zone is developed due to the multi pass welding degrades the heat affected zone properties very badly and sometime like say these cause the residual stresses, distortion and the type four cracking problems or reheat cracking problems. There are various

issue related with the multi pass welding also specially in case of the thick welding.

So both thin and thick and pro can impose various kind of problems even for the given metal which shows very good weldability under given set of the conditions when thickness is not, neither too low or not too high. So, if from this discussion if we see the weldability of the metal is not an intrinsic property of the material but it is influenced by the various other factors which are associated with the process procedure.

The purpose for which the joint is being made and the fabrication conditions under which it is to be developed. So, it is not an intrinsic property but it is a relative.

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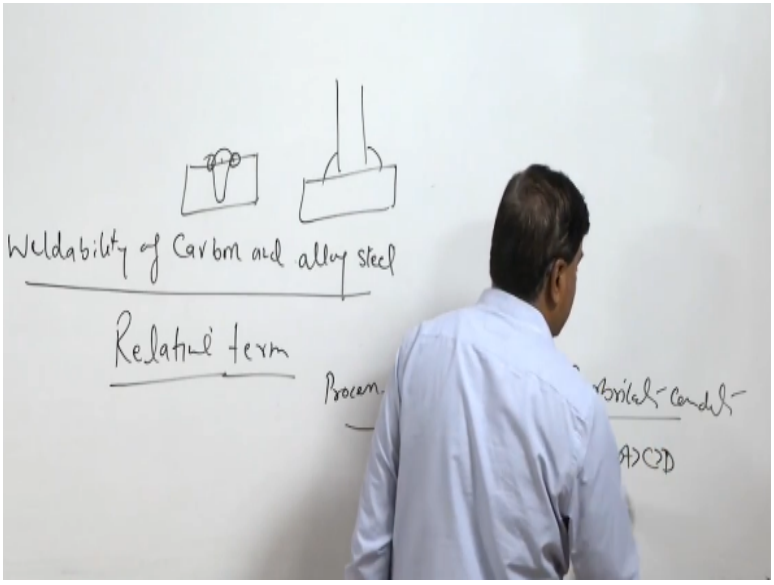

For a one set of conditions the weldability may be good for another set of conditions. So, it is kind of relative term indicating the ease of welding for a given set of the conditions. So, for the same set of conditions different metals are welded and then we may say that the A is good then better then B or B is better than A like that. But for that we have to define process procedure, purpose and fabrication conditions.

Under the same set of the conditions if the metal A, B, C, D are welded then definitely we can do some kind of ranking whether B is better than or A or A is better is then C and C is better than D like this. So, this will give some idea about the kind of ease of welding for the different metal

systems but it cannot be ranked in very absolute terms. It is kind of relative one. Now, the factors that determine the weldability as far as the metals are concerned. So, in general

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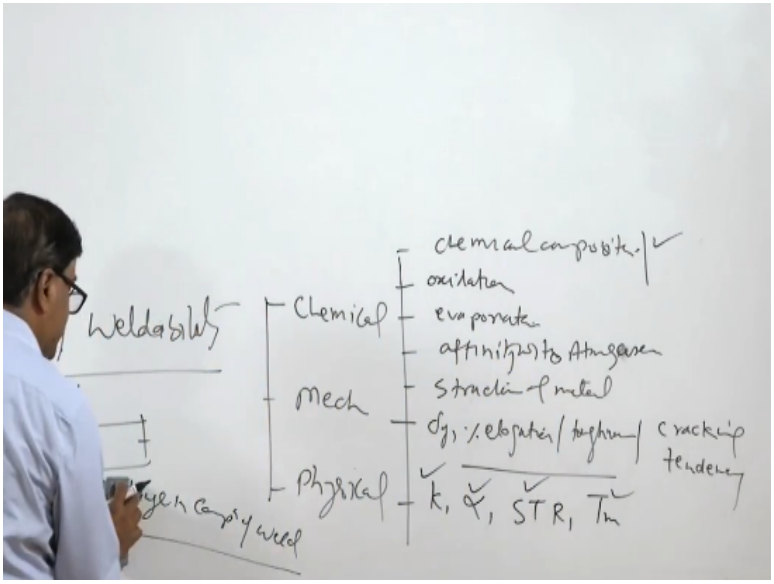

the metals and the weldability how are they related that is what we will try to see. So, we know that there are certain characteristics of the metals like chemical, mechanical, and physical. These properties of the material metals govern or affect the ease of the welding significantly. Like chemical is about the oxidation tendency. How easily it evaporates then affinity with the atmospheric gases.

Then the structure of the metal so these are some of the physical, chemical properties of the material and above one it is the chemical composition of the metal is one of the constituents or elements that are there. Among the mechanical properties we have the yield strength percentage elongation indicating the ductility of the metal and toughness. These are the mechanical properties.

These properties basically determine the cracking tendency. High yield strength, sorry low yield strength higher elongation and good toughness resist the cracking tendency. So, those metal which are offering otherwise different properties like high strength load, low ductility, low toughness they will show more cracking tendency. Similarly, the chemical composition effects the weldability significantly because it effects the solidification temperature range.

It effects the various mechanical properties and physical properties. Oxidation, the metals during the welding normally the metal systems are heated to the high temperature if they have tendency to get oxidized then we will see that the weldability is poor. If it evaporates the constituents in the metal, evaporate in course of the welding due to the high temperature then it will be leading to the difference in the chemical composition of the weld metal after the welding.

Like this is metal being welded so when it is exposed to the high temperature and the faying surfaces are brought to the molten state then some of the elements will be getting evaporated and this evaporation will lead to the change in composition of the weld metal. So, this change in composition of the weld metal will degrade the mechanical properties, corrosion properties and the tribological properties etcetera.

So, affinity to the atmospheric gases so those metal systems which has greater affinity to the atmospheric gases they will be experiencing more the inclusion and slag formation related issues. So they will be reducing the tendency for having the more inclusions at the same time they will have tendency to have more porosity. Structure of the material, some of the structure they offer very good toughness, good yield strength, good ductility.

So, some of the structures if the structural modification takes place in the material like when the base metal are welded the application of the heat, we will see that there is a change in structure of the metal near by the heat affected zone and mostly it is the corrosion that is encountered. So, the change in structure is very limited then the effect will be less otherwise the change in structure can affect the properties of the heat affected zone appreciably.

As I have explained the mechanical properties low yield strength, high elongation and the good toughness reduced the cracking tendency. So, that is why it is good from the welding point of view at least. And physical properties like K thermal conductivity, expansion coefficient, thermal expansion coefficient to alpha. Solidification, temperature range STR like temperature difference between the solidus and the liquidus, solidification temperature range.

So, these are the properties and apart from this like the melting point of the metal. In general, high thermal conductivity results in the lower weldability. High thermal expansion coefficient also reduces the weldability, longer solidification temperature ranges also reduce the weldability and higher temperature also reduces the weldability. I will explain how all these things are affecting to the weldability.

We know that for the welding purpose when we are applying the heat for the melting the faying surfaces then we will be seeing that

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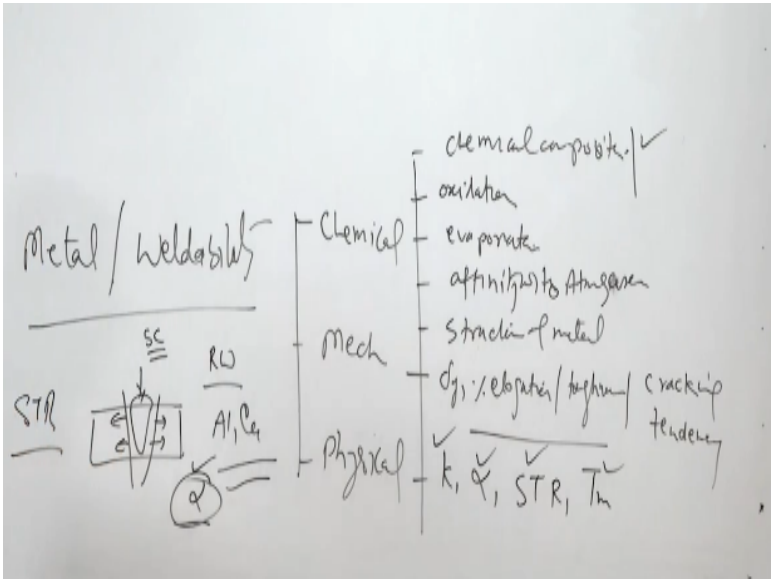

It will require more amount of heat because of the good K the heat will be transferred rapidly to the base metal. So, it will require more amounts of energy and longer time to reach to the molten state and increase the amount of energy, increased efforts, increased set of the conditions required for proper melting if the thermal conductivity is high. This problem is mainly encountered in the resistance building processes where very high current is needed.

In case of the thermal conductivity of the metal is high like in welding of the aluminum and copper it poses the problem related with the high current requirements for the welding purpose. Similarly, alpha thermal expansion coefficient, we know that during welding we will be applying heat and due to the application of the heat there will be expansion and contraction so higher expansion and contraction.

In case of the high thermal expansion coefficient metals will be leading to the more residual stresses and distortion tendency and that in turn will be reducing the cracking that will be in turn increasing the distortion tendency and residual stress development and thereby reducing the ease of the welding. So, high alpha is also not good from the welding point of view. Now solidification temperature range.

We know that if the solidification temperature increases then it primarily increases the solidification as well as the liquidation cracking tendency in the heat affected zone that is why it is not favorable to have the higher solidification temperature range. Then the melting point, if the melting point is low it is easier to weld because it will offer the lower, lesser amount of energy will be required for the melting of the faying surfaces and to develop the weld joint.

Otherwise we will require lot of energy for the melting purpose. It will require lot of efforts for the purpose of melting the faying surfaces of the base metal to develop the weld joints. So, this is how the metal characteristics and their possible effect on the ease of welding. But all this was very generic in nature.

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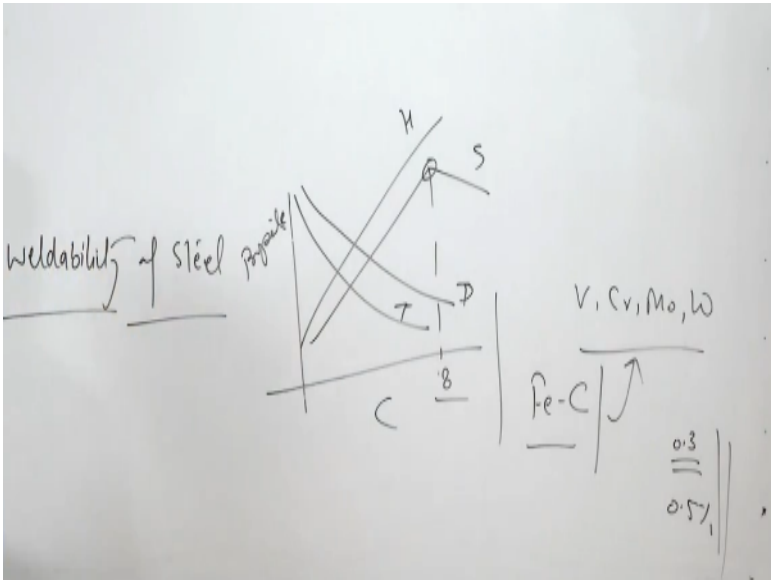

Now coming to the weldability of steels. So, whatever I have talked so far was the general aspects related with the welding. Now, the weldability of steels we know that these are alloy of

iron plus carbon. Carbon mostly occupies the interstitial space in such kind of alloys and in simple carbon steels mostly we have the carbon in very controlled conditions thereafter magnesium, silicon, sulfur and phosphorus.

All these are residual elements which are controlled within certain specific limits depending upon the kind of carbon steels. In carbon steels we mainly try to control the carbon only. Like say for low carbon steels we have carbons less than .2 for medium it is 0.2 to 0.5 and then for high carbon steels it is greater than 0.5. So, mostly the high carbon steels are found out to say 0.5 to 0.8 so this is the range for the different kind of carbon residue.

And it is the carbon content that determines the properties of the steels in case of the carbon steels but since the properties like the toughness and the ductility are very badly compromised with the addition of the carbon. This is what we can see as a function of carbon ductility and toughness come down while hardness increases continuously and the strength increase, first increase up to say 0.8% of the carbon.

Thereafter it starts decreasing so this is the hardness, strength, ductility and toughness. So, here we can say properties. So, to overcome this issue that with the very high carbon content although hardness increases but happens with the loss of the ductility and toughness and therefore efforts are made to put in the alloying elements in the steel like steel like vanadium, chromium, molybdenum, tungsten etcetera.

So, such kind of elements are added in steel. So, apart from the iron carbon we add the alloy steel. Sometime their carbon content, I mean complete addition is kept like say .3 or .5 depending upon the purposes. So, limited controlled addition of the alloying elements help to improve the strength without compromising much on the toughness and the ductility. So, in that case the steels are termed as –the alloy steel.

When for specific purposes like enhancing the strength without compromising much on the ductility and toughness alloying elements are added.

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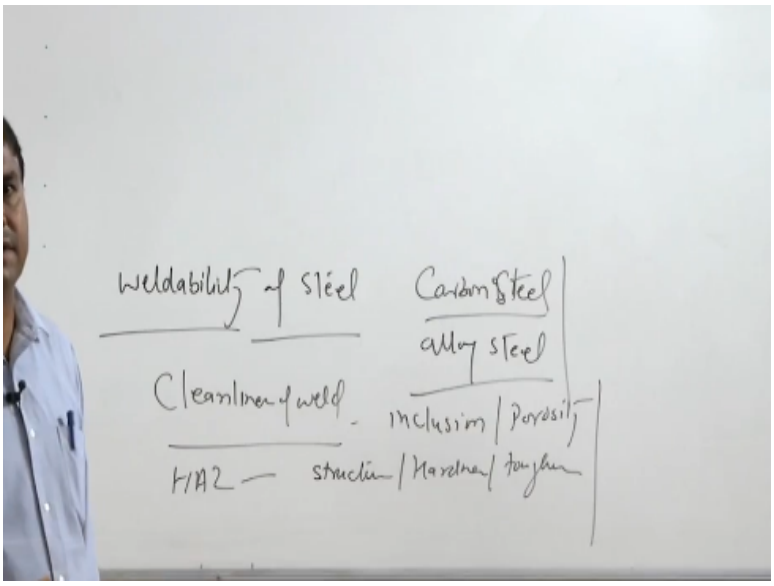

So we get the alloy steels. So, this is what is about the carbon, steels and alloy steels. And ease of welding in case of the steel is influenced by what? The two aspects like when steel plate is welded what we see after the welding that two aspects one is the weld metal. How sound weld metal is being made so it is about the how clean a weld is and another one in case of the steel it is primarily how about the properties of the heat effected zone.

So, HAZ properties these are the two important factors that determine the weldability in case of steels. So, the cleanliness of the weld means what? Cleanliness of the weld in case of the steel means it is about inclusions, porosity. And the heat HAZ properties in case of like the kind of structure hardness or the toughness variation which is encountered in the heat affected zone. So, these properties are governed by the various aspects for example cleanliness.

So, if the weld metal is very clean and heat affected zone developed after the welding of the steel does not have very uncompromising or very compromising properties then the weldability of the steel can be considered good. Because most of the time we see that heat affected zone properties are very degraded the joints becomes very brittle and unstable, brittle and with the limited toughness or with the very poor toughness.

So, here now I will conclude this presentation. In this presentation I have talked about the –I have tried to define the weldability term and the factors that affect the weldability as far as the

like those factors related with the metal systems and what are the aspects related with the weldability of the carbon steels and in which way the ease of welding of the steels is affected.

And what are the various factors associated with the steels that govern their ease of the welding that is what I will talk in the next turn. So up to this now, thank you for your attention.