Joining Technologies of Commercial Importance
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Lecture - 26
Explosive Welding

Hello, I welcome you all in this presentation, this presentation is based on the Explosive Welding process, this is another solid state welding process like ultrasonic welding process which about which I have talked in last lecture and this lecture is also in connection with the joining technologies for the metals.

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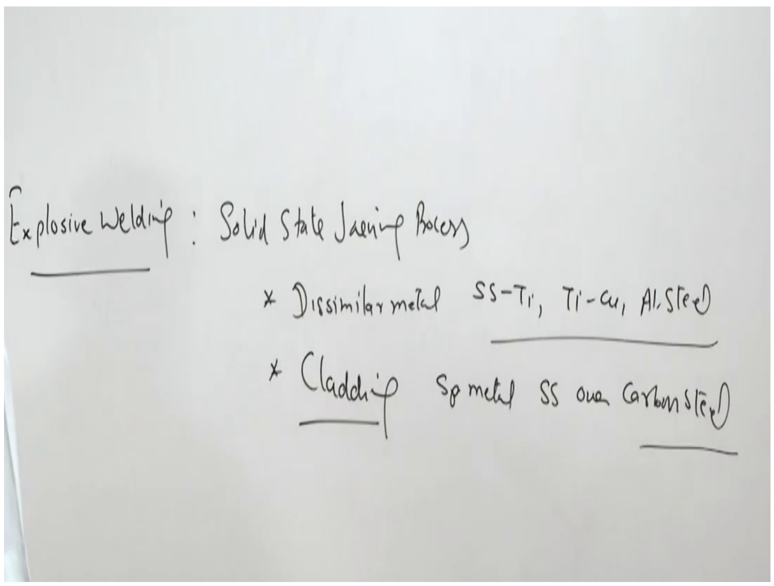

So the process is explosive welding process, this is another solid state joining process and this is primarily used for joining the very dissimilar metals which are not metallurgically compatible with each other like stainless steel, titanium, titanium copper, aluminium steel etc. so which are very dissimilar kind of combinations need to be welded, they are joined using this process.

And another typically used is for the cladding purpose when large area cladding is to be done cladding of the specific metal like a stainless steel over the carbon steel or any other kind of arrangement or the cladding is to be made then the explosive welding is used, so primarily this is another solid state joining process which is used for mainly joining the dissimilar combination which otherwise cannot be implemented or developed using the other welding processes.

And the cladding purpose for - for protection of the base metal from the corrosion or other aggressive environment. So now we will see how does this process working and what are the important elements related with this process so since the process is solid state and explosives are basically used for creating the conditions at the interface which will facilitate the development of the joint even in the solid state that is the purpose of.

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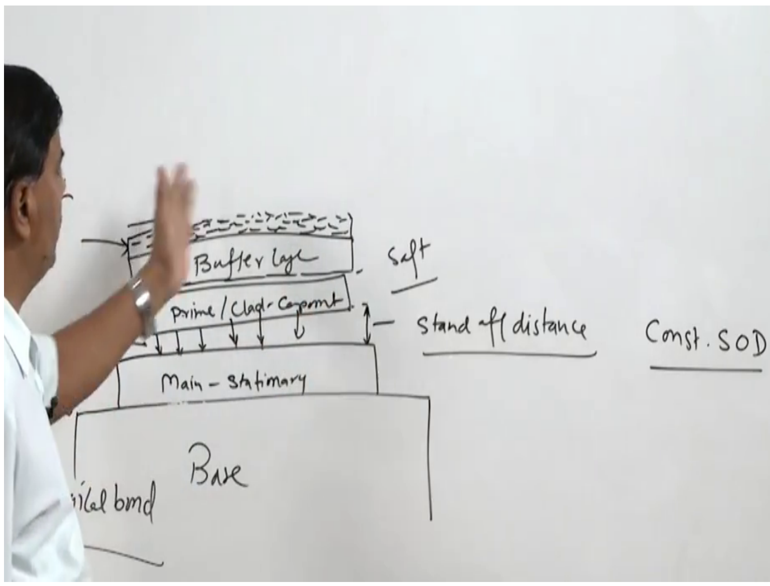

So here we will see very robust base is used which can sustain the heavy impact so which is created by the explosion, so the component to be welded is the component there is the one main component which you can say main component to which joint is to be made, so this is stationary it is kept on the base and another component which is to be joint is made the prime component like this it may be a cladding material or it may be another member.

So normally this one is made of either soft or any other cladding material which is to be joined, this is the prime component prime or clad - clad component like this, over this what we do either directly explosive plates placed or sometimes we place one buffer layer this is buffer layer, buffer layer actually protects the damage to the - the prime component or the clad component from the erosion due to the explosion.

And over this we normally distribute the explosive over the buffer layer or sometimes it is directly placed over the surface of the - the prime component right like this, so here we will see explosives is placed over the buffer layer or it is directly sometimes placed over the prime component, so there is a gap between the prime component and the main component or the clad component and the main component which is stationary this is called standoff distance.

This plays a crucial role in development of the sound weld joint in this case standoff distance is constant, so what we can say constant standoff distance in this case, otherwise it can be variable also if the prime component is kept at the at a particular angle, once the arrangement is made like this then the explosive is triggered or fired or ignited from the one end, so ignition of the explosive it is ignited.

So sequentially means the explosive front will be moving sequentially from one end to another like this, so the explosive will be sequentially moving from one side to another and as and when its explosion starts the - the prime component is pushed with - with huge velocity accelerated with the huge accelerated towards the main component or it is move towards the main component at a high velocity, so here its impact with the main component takes place.

And when the impact with the main component takes place, then here it will be causing first the due to the impact the heat generation and then huge plastic flow at the interface, so this these two conditions facilitate the development of the metallurgical bond between the members being joined, so what is important before - before explosion the prime component and the main component must be cleaned and made free from all the impurities.

So that there are no oxide traces etc. and so after explosion when the impact takes place with the sufficient high velocity the heat is generated plastic flow at the interface facilitates the metallurgical bond, so this is how it works in case of the constant standoff - the standoff distance, so in this case the plate will be moving from one end to another sequentially as the explosives will be - explosive will be burn or explosive ignition will continue to propagate from one end to another.

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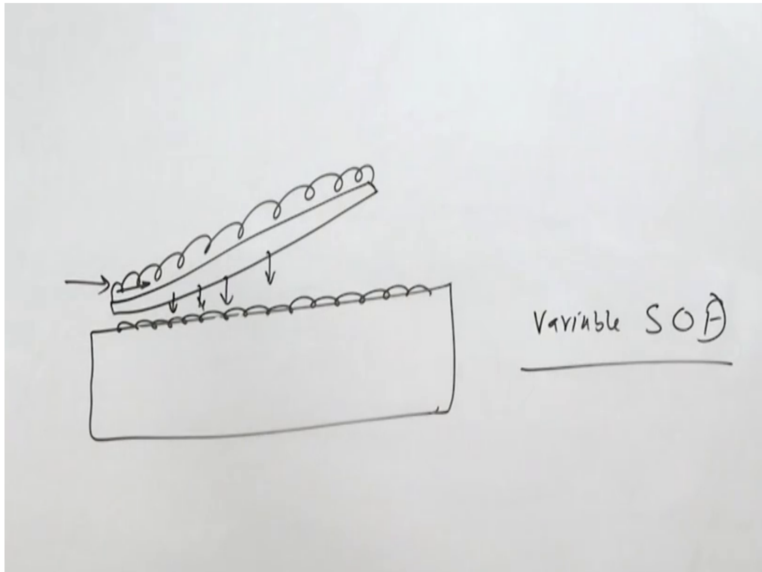

There is another situation where in sometimes in special cases if you want that impact of the prime component with the main component does not takes place in one go in that case especially the - the prime component is placed at an angle like this and this is the main component say to which the prime component after the impact, so there and over this we can and have either buffer plate or we can place the explosive over it like this.

Then in this case it is fired explosive is fired from one side or ignited from one side, so the explosive means the flame front or the - the explosion will be moving from the one end to the another pushing the plate sequentially down and so the bond will be formed also sequentially from one end to the another impact in one go of the entire prime component plate with the bottom one will be avoided.

So in some cases the variable standoff the distance - standoff distance arrangement is used instead of the parallel or the constant standoff the distance case.

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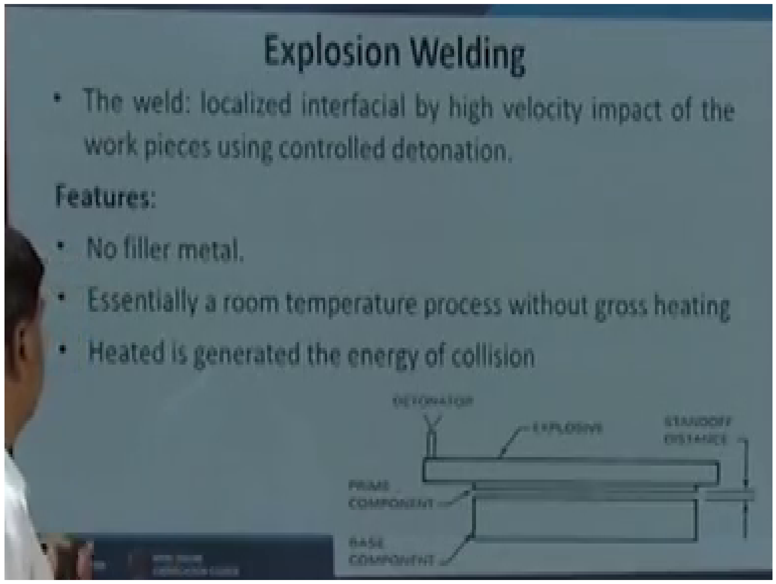

So here from the uniqueness point of view if we will see the localized interfacial deformation is facilitated by the high velocity impact especially of the prime component with the main component using the controlled detonation, there is no filler and there is no external heat application primarily bonding takes place at the room temperature and whatever heat is generated that is because of the impact and so heat energy is generated due to the energy of the collision.

So here we will see that the base component and the prime component and then over this explosive is placed and then detonator this side, the gap between the two is the standoff distance, there are two arrangements as I have explained as far as the principle of operation means the schematic arrangements for the placement of the plates are concerned like here the detonation this is explosive with the detonator at one end.

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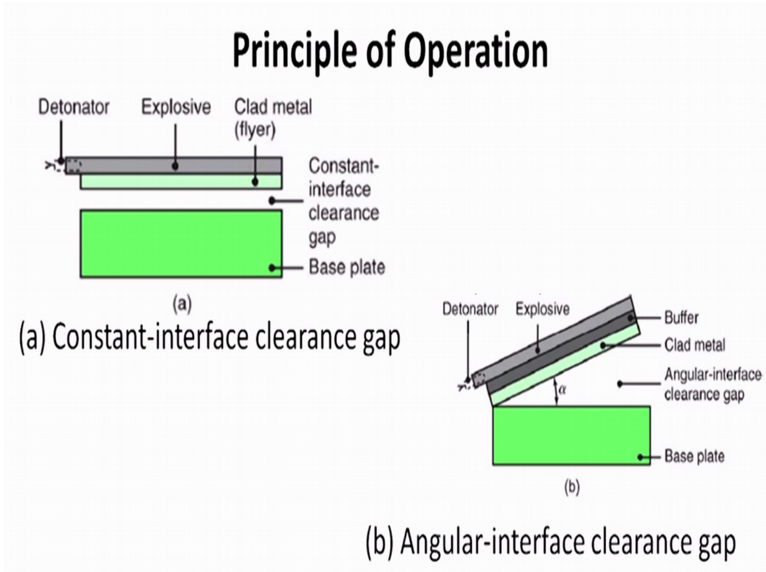

The cladding material or the prime component and the base component the constant interface clearance, in this case constant interface clearance gap or the constant standoff distance, in another case the buffer layer is placed in between to avoid any kind of erosion to the prime component or the clad material which is placed at certain angle is called angular interference clearance gap and then base plate.

So in this case it is fired and the plate is pushed sequentially from one end to another for development of the weld joint and here the plate is already kept at certain angle, so that when it is fired gradually it will be moving from one end to another.

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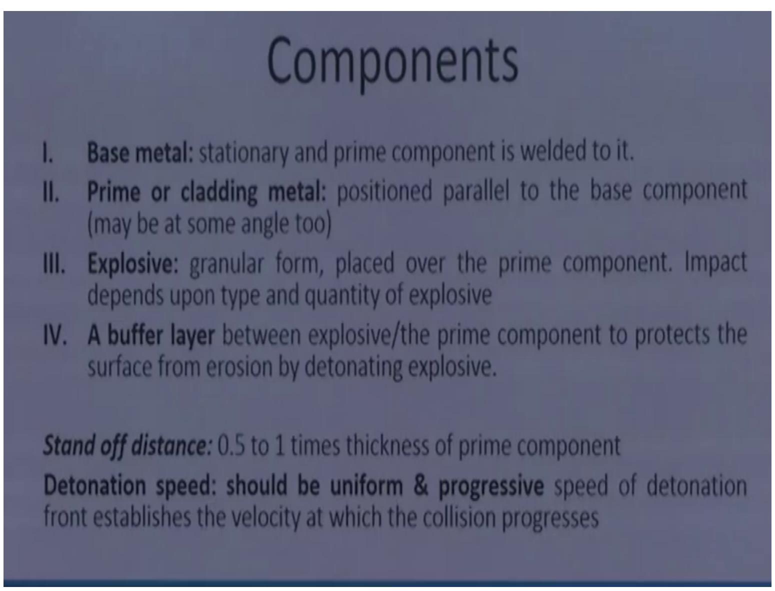

So if we see there are 4 components basically, the base material which is kept stationary over the anvil and the prime component which is welded and kept at the top prime component maybe another member or it may be in form of the clad material, the prime component or the clad material is positioned either parallel to the base component or it may be kept at certain angle depending upon the requirement.

Explosive normally, explosive which is placed is in - is in the granular form it maybe RDX or TNT or any other suitable form of the explosive which will can provide the sufficient amount of the energy for explosion and moving the plate at sufficiently high velocity, so explosive in granular form placed over the prime component and impact magnitude with which the prime component will be impacting with the surface of the base metal will depend upon the kind of explosive being used and the quantity of the explosive which is being used.

And the buffer layer sometimes is placed between the prime components in explosive to protect it from the erosion when the explosives detonate. Standoff distance normally kept at 0.5 to 1 times of the thickness of the prime components so this is crucial, because it will facilitate the time which the standoff distance will affect the time for the movement of the prime component towards the base plate.

So, normally as it has been mentioned this standoff distance this gap can be equal to the 1.5 0.5 times to the 1 time of the thickness of the plate and detonation speed should be uniform and progressive speed of the detonation front establishes the velocity at which the collision will be taking place.

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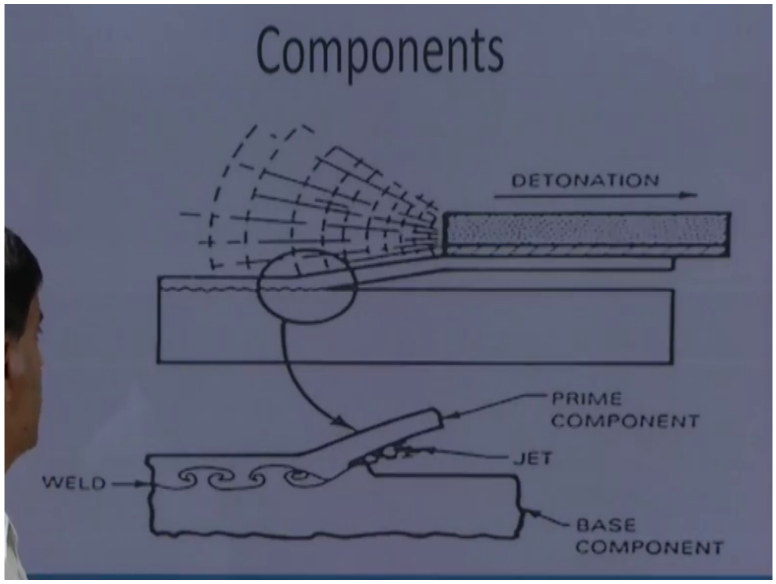

This is what we can see here, this is how the collision - the ignition starts and it propagates from one end to another and this is the we can say in this portion already the explosion has taken place or detonation has taken place and with the impact the prime component has impacted with the base metal and it has been welded and this is what in enlarged view we can see the prime component in the upper one and the base component lower one.

And forming the wavy structure at the interface about which I will talk, so in course of the determination as it moves from one end to the another gradually the joint is formed even when the standoff distance is constant, but the joint progresses from one end to another as the detonation progresses from one end to another. So here now we will talk little bit more about the interface, the features of the interface.

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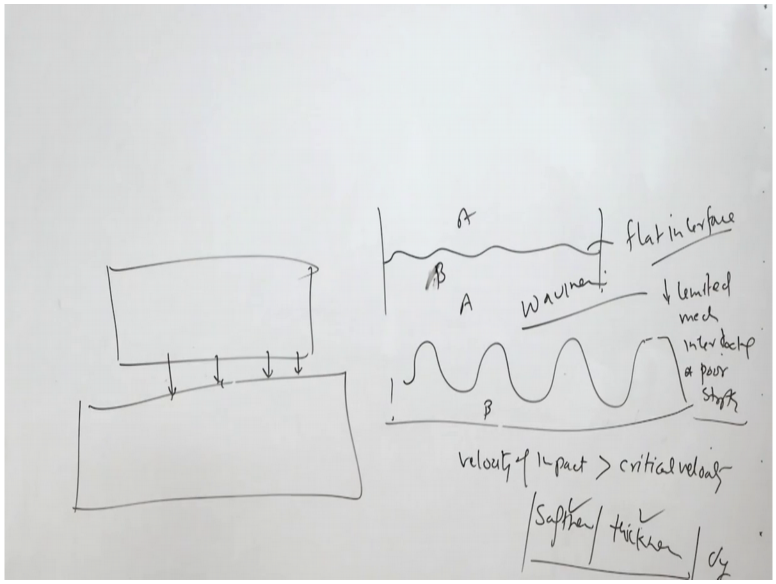

Normally, when the let us say this is the prime component and this is the main component after the explosion prime component impacts with the surface of the base metal, so after the impact sufficient heat is generated huge impact causes the plastic flow of the material at the interface and this in turn causes the interface of the wavy in nature like this, so this kind of nature like this side A metal and this side B metal.

So A metal penetrates into the B and B penetrates into the A, this kind of waviness is good for the strength of the joint, so greater is the waviness greater will be the interlocking or the strength of the joint and this happens only when the velocity of impact is greater than critical velocity for given metal systems, given metal system like softness of the - softness or hardness of the components involved, the thickness of the - the plate involved especially in the prime component and the softness thickness and the yield strength of the material.

So greater will be the resistance for the plastic flow of the material, higher is the - lower is the hardness soft will be the material, easier it will be flowing so thickness yield strength and the softness will determine the what will be the critical velocity at which the waviness will be present, otherwise interface can be literally flat and the flat interface having A one side and B another side this is B and this A.

So in this case limited waviness will be producing the flat interface and flat interface is not good for from the two aspects due to the limited - limited mechanical interlocking this is one and the two is the poor strength so and this especially happens means the flat interface is formed especially when the velocity of the impact is less than the critical velocity of the - the prime component.

That is why the sufficient velocity must be attained by the prime component in course of the explosive welding, otherwise the - the waviness of the interface will be very limited and the flat interface will be formed which will limit the strength of the joint bond and the joint will tend to get break especially under the moderate loading conditions due to the poor the bonding and the joint strength.

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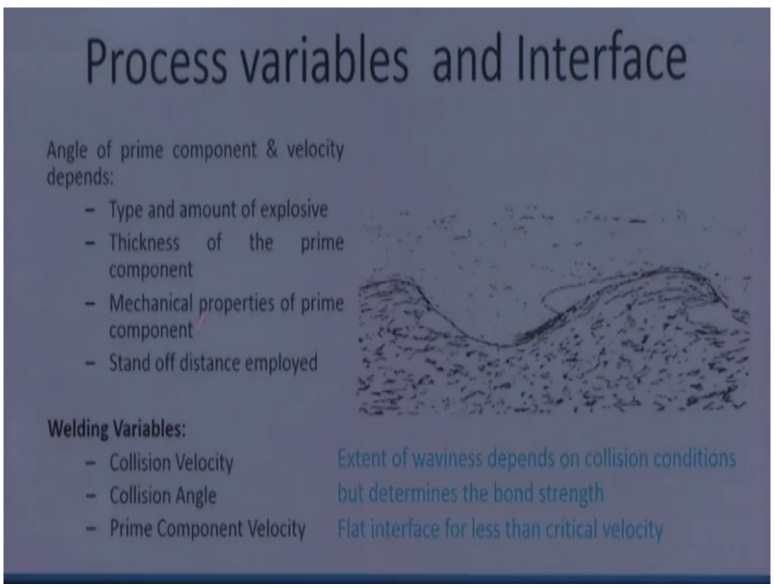

Thus so if we see here the angle of - so the - the angle at which prime component is replaced and the velocity at which it should impact depends - this will depend upon the how much amount of explosive and the type of explosive has been placed greater the amount and explosive of the higher energy will be offering the greater impact velocity.

So the thickness of the component thickness of the prime component thicker will be the plate higher will be the impact velocity requirements as compared with thin plates the mechanical properties of prime component higher is the hardness and higher is the yield strength greater will be the impact velocity requirements for having the sufficient waviness at the interface so that the good mechanical interlocking and the bond strength can be achieved.

And the standoff distance, so standoff distance must be optimally selected so that it impacts with the sufficient velocity which is greater than the critical velocity requirements for development of the sufficient joint of the sufficient strength, so the extent of the waviness depends upon the collision conditions especially the impact velocity which in turn determines the bond strength.

So flat interface in general if the velocity is less than the critical velocity then it offers the - the flat interface and which in turn will be lowering the strength of the joint.

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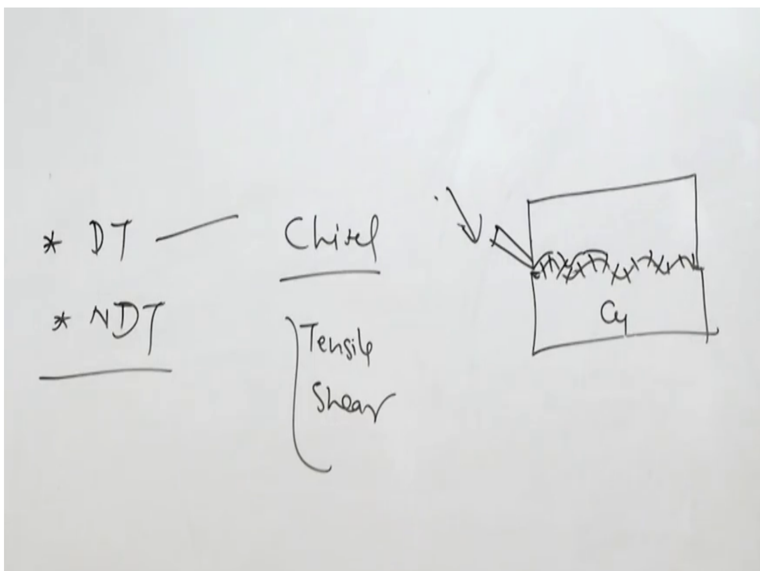

So how to assess the quality of the joint so for assessing the quality of the joint normally both destructive test and non-destructive tests have been developed, so one typical one about which we can talk is like under the destructive test is one is chisel test, another like the tensile and the shear strength tests so these two are very common.

But the chisel is unique one about which I will talk little bit like say this is the - this is the copper and this is say the titanium and the joint has been developed using this explosive welding process like this, so what is done basically when chisel is applied here and then the efforts are made to break the interface, so with the application of the chisel, when chisel is applied hammer is applied chisel is placed at the interface and then hammering is done.

So if the - if the separation takes place across the interface that will suggest that bond strength at the interface is poor, otherwise if the failure takes place from the near locations of the interface fracture or the failure occurs from the locations near the interface and that will suggest that bond strength is really good this is one typical example, in chisel test no separation at the weld interface.

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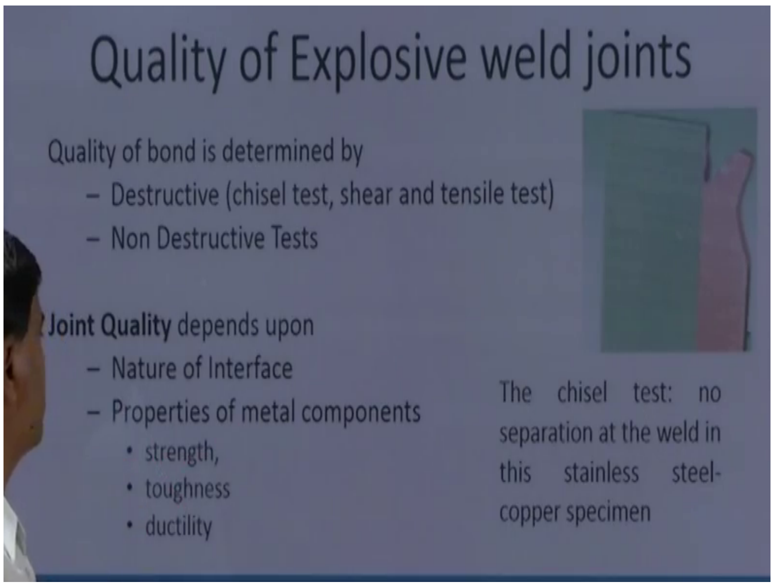

In case of the stainless steel copper joint say this side we have copper, this side the stainless steel and chisel test is conducted, so this in the interface is still intact but the failure starts from the copper side, so this is one typical test which is and the unique one and mostly accepted for that explosive welded joints.

Other tests are common one like the tensile and shear test for checking the mechanical capabilities or load carrying capabilities of the joint explosive joints under the tensile and the shear conditions.

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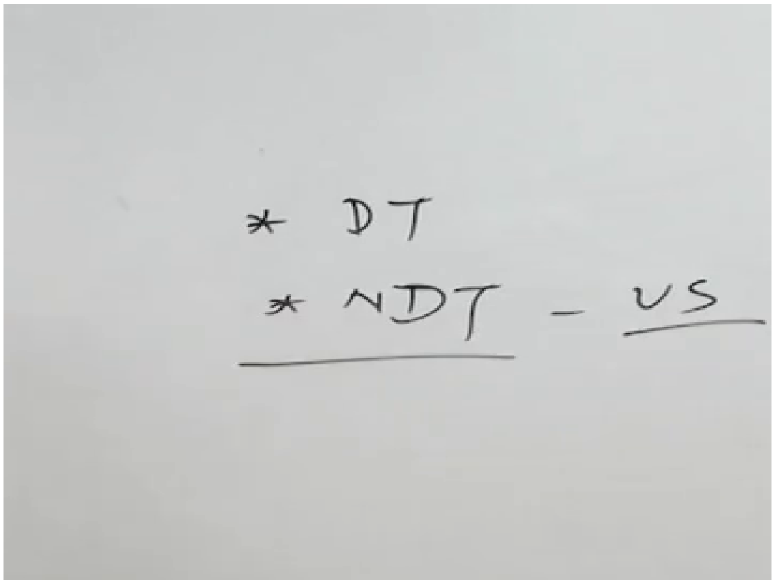

This kind of the joints means the soundness of the interface can be tested from the ultrasonic method - ultrasonic test for determining the soundness and similar other entities can be used for determining the soundness however there may be problems if like at the interface if some gaps are left then those can also be highlighted in under the ultrasonic conditions.

So the joint quality means the load carrying capacity of the ultra - explosives welded joints is determined by the nature of the interface means whether it is flat or the wavy, in case of the wavy interfaces of course their strength is good as compared to the flat and the properties of the metal component also affects the soundness at the joint strength. So higher is the strength limited will be the joint strength.

Higher is the strength of the base metals limited will be the joint strength of the explosive welded joints, because of the deformation and interlocking in that case we will be very limited, so likewise the other properties also affect the - the strength of the explosive welded joint.

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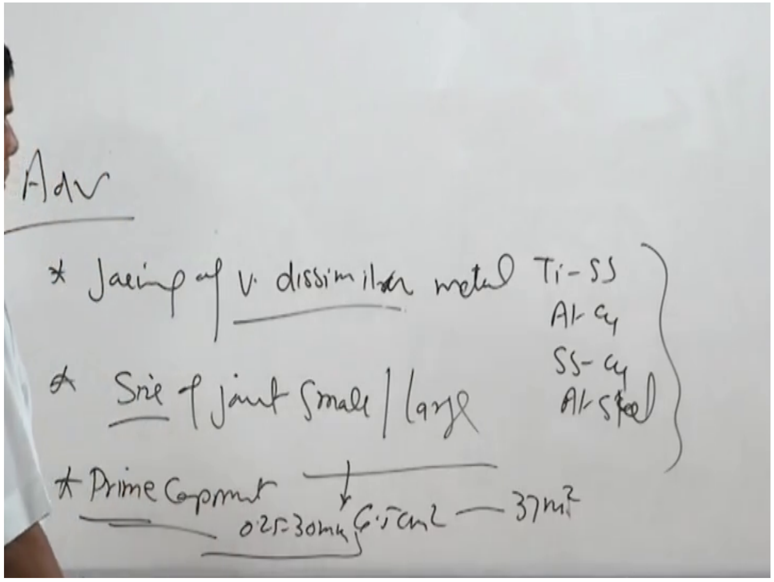

Advantages, since this process does not involve any external heating and no fusion no mixing of the different metals so the process is effectively used for - the for joining of the very dissimilar metals, so the thing is joining of very dissimilar metals can be achieved - dissimilar metals can be effectively achieved like titanium, stainless steel, aluminium, copper and stainless steel, copper aluminium steel etc. so these are very dissimilar combinations which can be joined.

Further the area of the joint - joint size it can be the joint area or the size of the joint it can vary from very small to very large so this is one which we can be highlighted from like say the large size range of the joints starting from say 6.5 centimeter square to 37 meter square, so very large size joints also can be made using the explosive welding technically there is no upper limit and thickness of the joint which can be made using this process.

And the typical thickness of the joint which can be made of the prime component, so prime or the clad components thickness is limited to like say it is a 30 mm is the upper side 0.25 mm to 30 mm is the thickness range which can the range of the prime component which can be welded using the explosive welded joints. So these are some of the advantages related with the process -the process.

And the some of the limitations like the component to be joined must be robust enough to handle the impact, otherwise it can distort it can get change the shape so it must sustain the conditions which are being used under the explosive conditions, so they are two main factors related with the limitations one is it is limited to the lap joint configuration for developing the clads.

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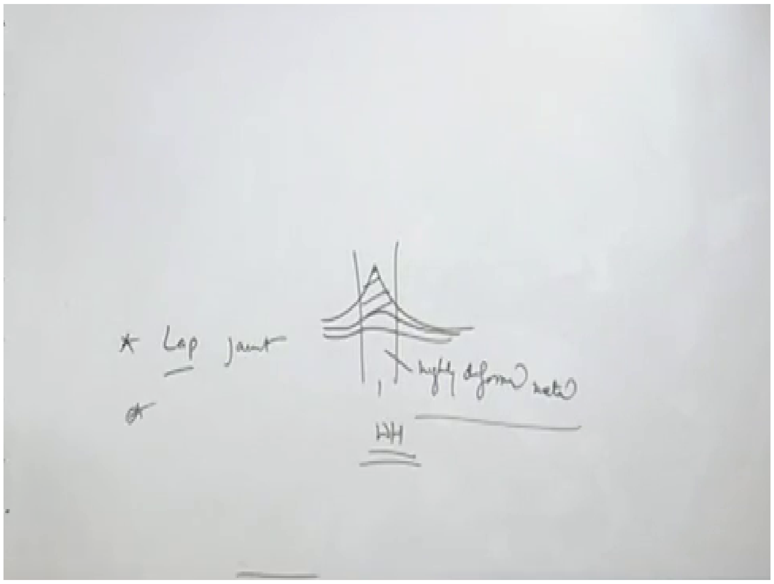

So one is the limitation of the lap joint configuration and the second is limited to the flat plates cylindrical and the conical structures, so not very complicated geometries can be joined using this largely the simple shape components and in lap joint configurations, the joint can be made using this process. This diagram shows the very the combination of the metal system which can be joined using the explosive welding process.

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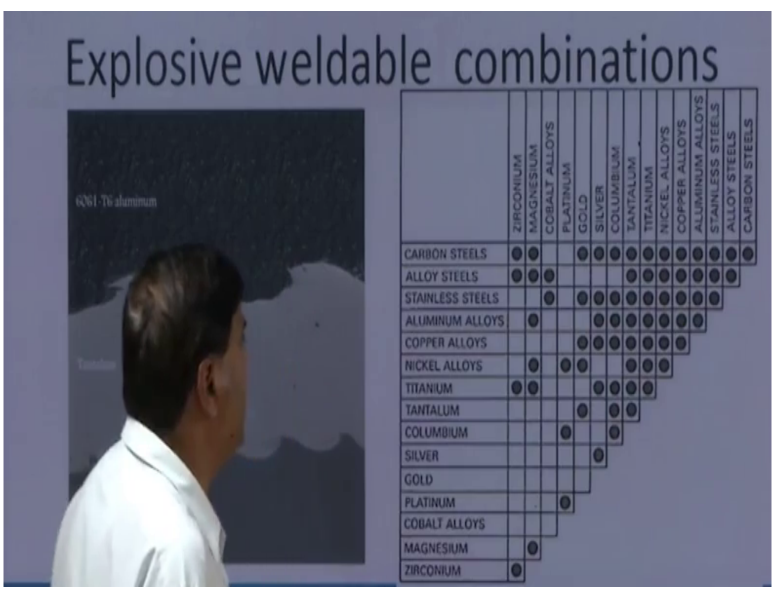

And we can see there are certain metal systems in the y axis and the certain metal systems in horizontally means certain metal systems mentioned vertically and certain mental systems mentioned horizontally and the wherever the combined - wherever the dots are present that shows the combinations which can be welded using the explosive welding process. Say carbon steel with zirconium, carbon steel with magnesium, carbon steel with the gold silver columbium, tantalum, titanium, nickel.

All these are welded with a carbon steel similarly alloy steels with all these systems if you take columbium, columbium can be welded with the platinum and also with the columbium on its own. So likewise there are different metal systems depending upon the hardness and the extent combinations with the prime component main component the various combinations are available which can be joined together using the explosive welding process.

So here typically what we can see the kind of waviness which is present and this waviness shows or determines the strength of the explosives joint. If it is largely flat then the flat interface will offer - be offering lower strength as compared to the wavy structures, so here if we see - here if we see this is the region where the plastic flow of the material will be taking place, so this plastic floor of the material will be causing the work hardening of the material.

So at the interface if we check the hardness of the material at the interface it is always higher than like softness then interface hardness and then again the softness, so this interface will be having the region of the highly deformed metals and highly deformed metal is subjected to the work hardening, so work hardening actually increases the strength. And subsequently if the system is normalized are heat treated stress is relieved than maybe this one gets moderated or it gets flattened.

And so there is no major variation in hardness is left because all work hardening effect is eliminated through the heat treatment process.

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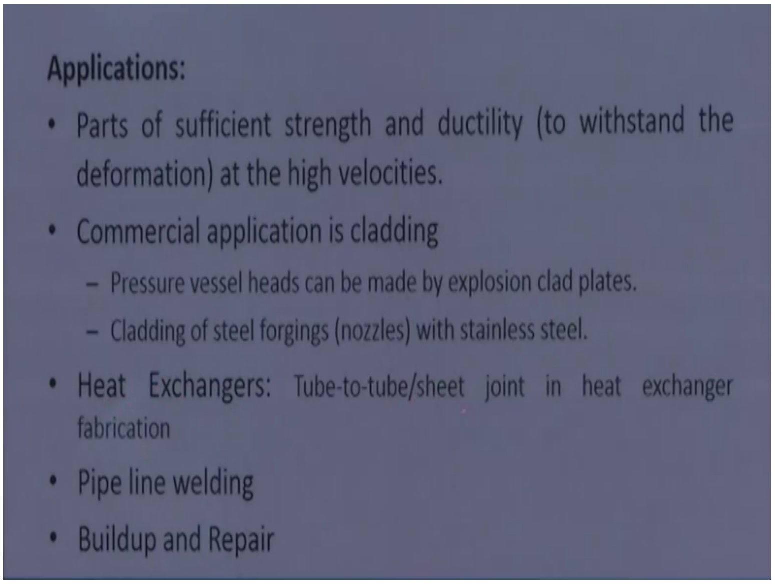

So these are the typical applications of the explosive welding process mainly used in commercial applications is cladding, pressure vessels heads can be made by explosion clad plates, heat exchangers like tube to tube and sheet joints in heat exchanger fabrication, pipeline welding, buildup and repairs, and such of these are the various applications where explosive welding processes - process can be used.

So here now I will summarize this presentation, in this presentation I have talked about the basic principle of the explosive welding process, the factors that governed the soundness of the weld joint and the role of the interfacial structure and the factors related with the interface and its effect on the joint performance, besides the advantages and limitations of the process, thank you for your attention.