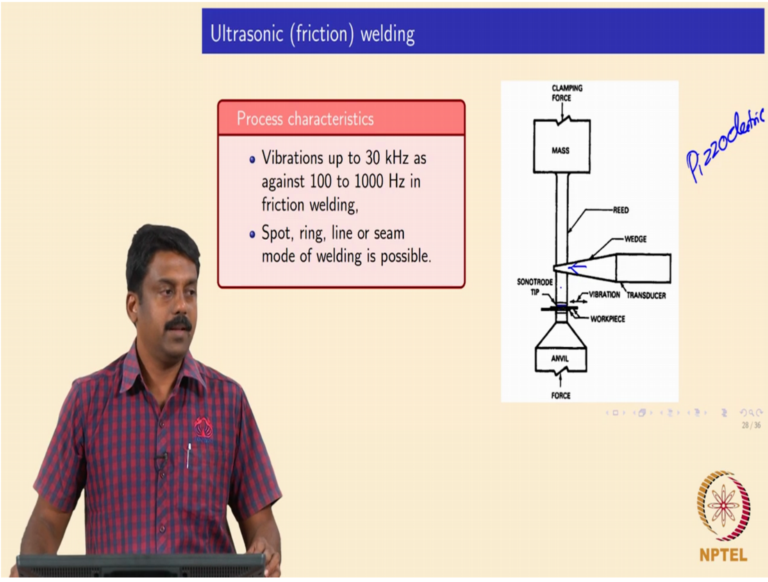
**Welding Processes**
**Professor Murugaiyan Amirthalingam**
**Department of Metallurgical and Materials Engineering**
**Indian Institute of Technology, Madras**
**Other Solid State Welding Processes**

(Refer Slide Time: 0:20)




So, we will move onto the next welding process. Any questions so far? So, the other solid-state welding process which again uses friction as a heating mechanism, but in this case we use ultrasounds to vibrate the interface. Okay. So, in ultrasonic welding, so we use the ultrasounds using a transducer. What is a transducer? Piezoelectric, what do you mean by Piezoelectric it is Piezoelectric, right. What does it do?

Student: Mechanical to electrical.

Professor: Mechanical to…?

Student: Basically it converts one form of energy to another.

Proffessor: What is the form of energy? Yes, here electric energy is converted mechanical energy. So, the Piezoelectric transducer generates the ultrasound waves through by applying an high-frequency current we can also achieve high-frequency vibrations. Is not it, so this transducer generates ultrasound waves, which can be transmitted using a waveguide to the interface, okay. So the setup looks like this. So, here is the clamping force using a mask and then transducer wedge and the waveguide transmits the ultrasound waves and the vibrations to the interface, okay, the tip of this electrode.

And then the interface is vibrated with the ultrasonic frequency. Okay, so we have this setup in our welding lab, ultrasonic welder. So, once you start vibrating at the ultrasonic frequency locally, you heat up the interface, okay, so you cannot supply a downward force, either by using a roller or a simple mass, okay. And then when the material is heated up locally, you apply a force, downward force so that the interface can be joined. Right. So, generally the vibration frequency is about 25 kilo hertz to 30-35 kilo hertz. So, that is most commonly used but much higher frequency can also be used.

Okay, so the conventional, like what we have in our lab, it can go up to 30 kilo hertz. Right, so 25 to 30 kilohertz it can go. And much larger frequency can also be used but those are expensive, we need a very high-capacity transducer to generate high-frequency, very high-frequency ultrasonic vibrations. Okay. And you can do it in a spot configuration because we have a transducer and we have a roller attached to that and you have of continuously, okay.

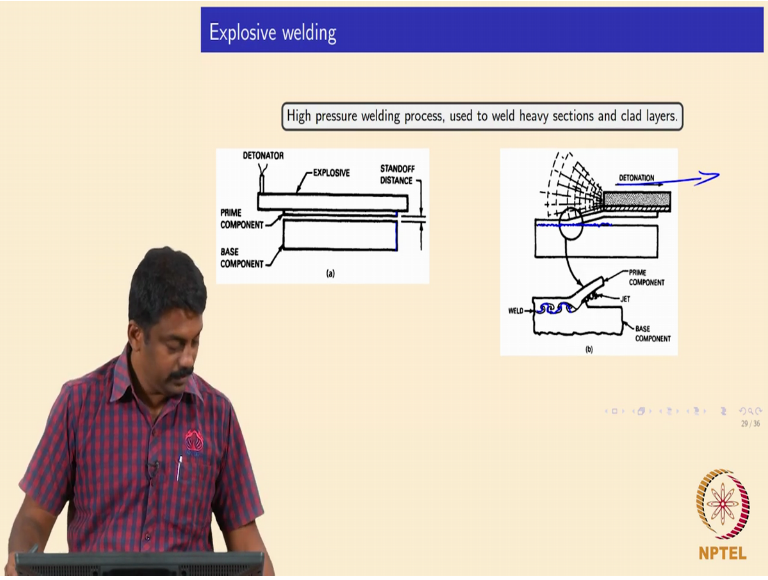
Transducer vibrates and then roller can apply downward force and you can make a seam welding. Right, so you can look spot weld or ring weld as well, line weld, seam weld and you can also build up layer by layer. The main advantage of this, one is, so you would deform very locally, so the Thermo Mechanical affected zone and the still zone becomes extremely small, because vibration happens at the interface in a very small area. Okay, so the interface is highly localised, the deformation is highly localised in ultrasonic welding.

So, you minimise the still and Thermo Mechanical affected regions. But main disadvantage of this process is you can weld only thin sheets, okay because you cannot really make the ultrasound travel through the thicker material because it attenuates, is not it, the vibrations and the ultrasound. So, for thin sections, for thin sections, very soft material, say 200 micron, 400 micron thick aluminium sheets, we can weld it. Until one may come up to 800 to 1 millimetre, 800 microns to 1 millimetre, we achieve welding.

But generally it is advisable to do it for foils, okay, so welding of thin foils. Okay, so this process is very widely used, especially the 100, 200, 300 micron thick aluminium sheets. Right, is it clear? Ultrasonic vibrations, so the parts are the transducer, which generate ultrasound waves and then these waves are conducted through a wedge and a waveguide towards the electrode on the trip, transmits the ultrasound waves and the vibration to the interfaces and we can apply simultaneously a downward force on the interface.

So, the interface heats up by the vibrations, the vibrations generated heat and simultaneously you apply a load and that load can cause local deformation of interface and the welding is done by Mechanical deformation. It is clear. No liquid, nothing, metal just heat up significantly because deformation is very localised. Good.

(Refer Slide Time: 5:38)




So the other process explosive welding and this is fun. Okay, this process is really, it is really fun, because we use explosives, really, bomb, okay. So various explosives we can use. So, what it does actually, so we have the base component and the prime component. So what is based component? Base component is generally a thicker section and we want to have some material deposited and weld it on the top of the base component. Right, so it is called prime component. So, you attach an explosive on top of the prime component and you keep some centre distance. Okay, because it has too upset with a very high velocity, so that you have a joint.

And the explosive generally you know various explosives we can use it, TNT is very commonly used. So, TNT is, was the 1st stable explosive that was invented. Before that the explosives cannot be stored okay, it was dangerous. So, TNT was the 1st explosive which could be stored, unless you detonate, it is not going to explode, so it can be transported easily, it can be carried to our friend easily because it is not going to explode on the way. So, this was just carried during First World War, it caused so much damage.

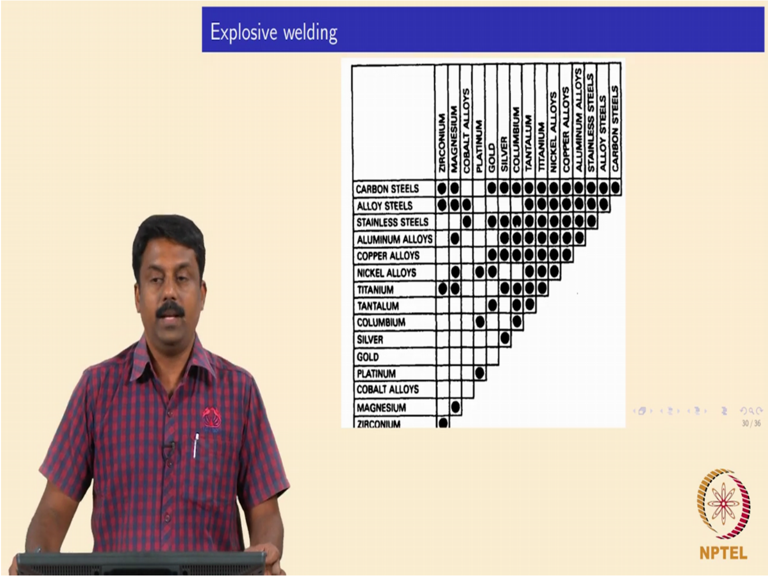
That is why all Alf Noble ended up giving all his wealth to charity. Okay. So, this joint is made in our campus. Okay, I said in the last class, okay, so this aluminium and this copper, explosive welded joint. So, this is the base component, right and this is a prime component and we pack explosive on the top, okay. So, you see that, I mean this is perfect joint, I am into a chief such a configuration as a joint, it is possible by any other way. So, nowadays you know, you can, even if you use a very strong high electric hydraulic upsetting force, you are not going to achieve a perfect joint between the base and prime. Right.

So this is possible, because of again the high-pressure, that is actually caused by the explosion and we can weld very heavy sections and clad layer. Okay, so this is copper and aluminium, so even if you deposit continuously the copper or aluminium, which is impossible to achieve such an Integrity at a joint, okay. So, you may also have during the (())(8:17) you have copper Filler deposited by GMA W process, it will also affect the microstructure beneath the interface, right.

So the joint property, joint efficiency is going to decrease significantly. Okay. So, generally what we do is, we have a detonator, explosive is packed on top of the prime, maintains stand-off distance and you clamp it, the base component firmly and then let the explosion happen sequentially from the detonator, so it can move along the direction, so you make the the prime layer, deforms and upsets with the base component and make a joint continuously.

And locally you will have a mechanical deformation, very severe deformation, the strain rates can go much higher than 10 power 3 or 10 power 4, right. It is even higher based on the explosion. Okay. It is clear. So, the explosion welding can be used especially if you are building a thicker section to weld the clad layer and it is very neat, I mean it can be done at one go, okay. So for example in this case, copper is here is about 10 MM and this can be about 30 to 40 MM. Even much higher, I think it is more than 25-30 MM. Right, so we can deposit glad onto the base component using explosion. Right, good.

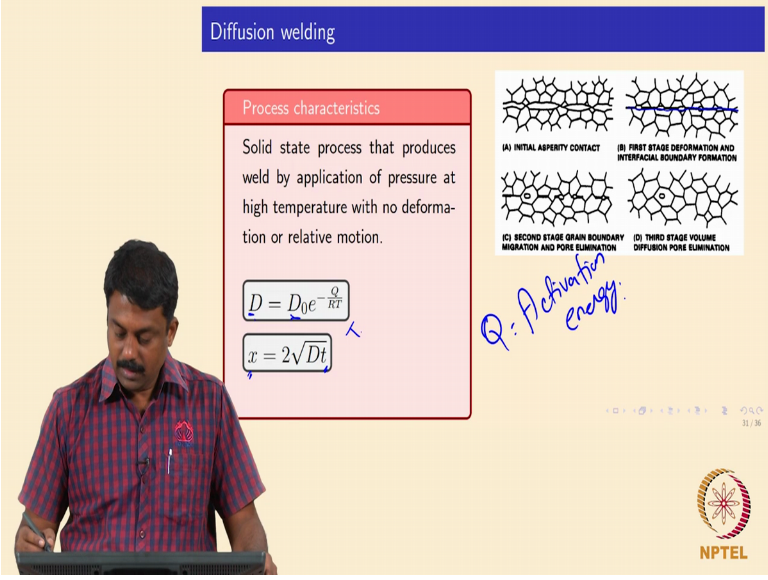
(Refer Slide Time: 10:10)




Any question so far? Good, we will finish. So, these are the possible combinations you can try. Right. So, using explosive welding. And here again, the materials would have some ductility, is not it, if the material is harder, you cannot make a uniform interface. So, hard material, for example ceramics, they cannot be exclusively weld, is not it. And it has to go plastic deformation, like in this case I showed you over here. There must be mechanical flow, is not it. Right, good.

So, you can look at this table, this stores the norms. So, there is zirconium, zirconium can be welded easily. And zirconium cannot be wooden with any other material, okay. And zirconium can be welded using explosive, zirconium is used in various applications in nuclear reactors. Carbon, steals, zirconium, yes, you can look at it by yourself. So, there is stainless steel, various combinations possible using explosive welding. Okay.

(Refer Slide Time: 11:12)




Now we will move onto the next process, diffusion welding. Okay, so diffusion welding works on a simple principle that, so there is always a solid-state diffusion of atoms from one interface to another interface, is not it. So, then you have a composition gradient, you have aluminium and copper. As long as there is potential for the copper atoms to migrate to aluminium and aluminium to migrate to copper, we always have interface migration of atoms, from (())(11:43) interface, given by these Arrhenius principle.

What you have is the diffusion, flux is proportional to D0, diffusion coefficient, times, exponential times, okay, activation energy developed by RT, gas constant and temperature. Right. So, you always have migration of items from one interface to the other interface driven by the activation energy Q, so that actually is driven by the composition of gradient. Right. So clear. So, diffusion distance is determined by the diffusion coefficient itself, is not it.

And the distance at which the item can travel a given temperature T for a given time t small t, the distance the atoms can travel his remain free path, is not it, 2 times square root of Dt, right. So this can be used to measure the interface thicknesses when you are doing a fusion welding, okay. So, for example, you have an initial asperity, so you have 2 material and if you look at in an atomic configuration, this is how it looks like, this is 11 surface roughness, right. And you clamp this to material together. And you will have some clamping force causing the deformation at the grind level. Is not it.

And you make sure that you have the initial deformation and then you have the interface burnt deformation. Right, you have questions?

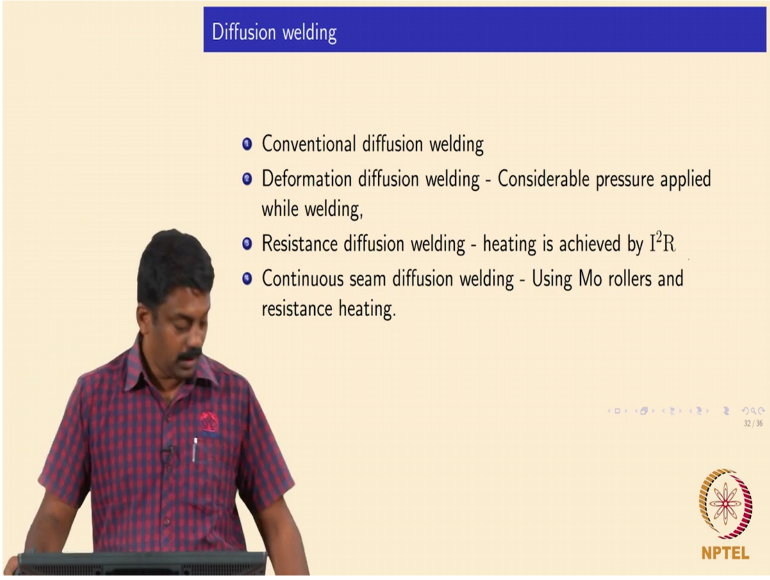
Student: What is Q?

Professor: Q is the activation energy for migration. D0 is the diffusion coefficient and this is the diffusion flux, Q is the activation energy. You have the initial deformation causing the interface formation and then once you have atomic flat interface, so you start heating up, the temperature can increase the flux, the movement of atoms from one interface to another interface given by this equation. Yes, it is clear? Good. And the principle is very simple and you cannot in this case weld when the material when the atoms of one interface cannot dissolve in the other interface, okay, it is very difficult to do that, right.

Especially seen in aluminium, iron and aluminium, okay, the dissolution of aluminium in iron is always higher than the iron in aluminium, okay. So, you always have one interface migration. So, you have to make sure that the atoms should form some solid solution initially. So, otherwise you cannot make a diffusion welding, diffusion bonding. Okay. So, once you have an atom migration takes place you have a grain boundary migration in the pores will be elaborate because you will have diffusion of atoms leading to a continuous interface formation.

And finally you will have, 3rd State you will have a volume diffusion forming and a complete interface disappearing upon sufficient diffusion of atoms from the interfaces. It is clear. Diffusion welding. This can happen at, so yes, it is reasonably at low temperatures compared to frictional steel. Because if you are keeping at low temperature, you will have to keep it for longer time, so you can achieve the X, the mean free path. Right, so we can also apply the varying amount of force and increasing the flow will obviously maximise the, in the interface and elimination, is not it.

(Refer Slide Time: 16:01)

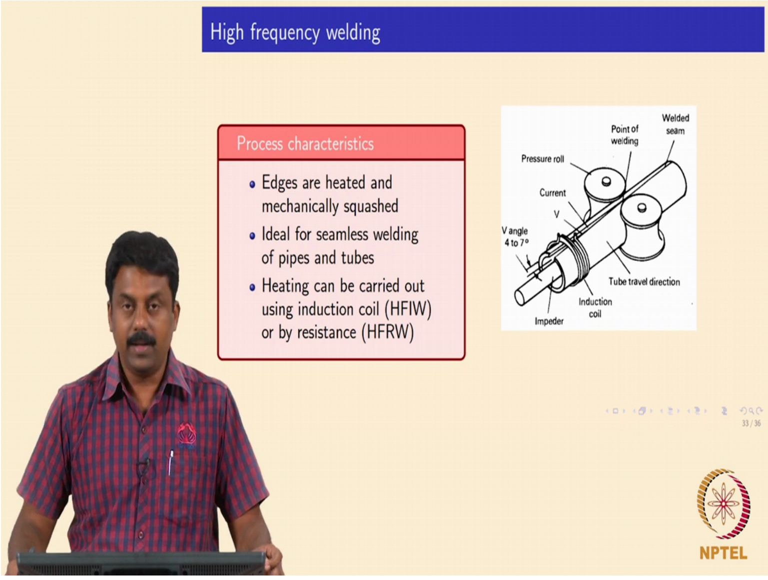



Okay, good. It is clear? It is a very simple process and there are limitations, okay, based on the nature of material we are going to use and as long as you make sure that there is a proper flux and compositional gradient leading to diffusion of one element to another element. Okay, there must be some solubility, of a given item in the other matrix, otherwise you are not going to achieve diffusion welding, right. So, the diffusion welding can be you know conventional diffusion welding square, you just need to keep 2 interfaces, apply some load and diffuse.

And you may also add an additional driving force for the migration of atoms by the mechanical deformation. Is not it, you apply considerable amount of pressure, so that there is additional driving force in the material can be formed and that can enhance the weld joint formation in some fast time, Quicker. And you can also apply some current during this diffusion process and you also have some heating generated at the interface, which should cause diffusion to happen much faster.

So, that is the resistance diffusion welding. Okay. So, you can also do a continuous rewelding, so you can also have electrodes rolling and at the interface and you may also pass a current in the electrode, causing the interface to form much faster, okay. You can also achieve a continuous seam within the electrode rolling, right. It is similar to what you see in resistance seam welding. But in this case there is no offsetting, okay, so only diffusion but it will be very slow process. Right, good.

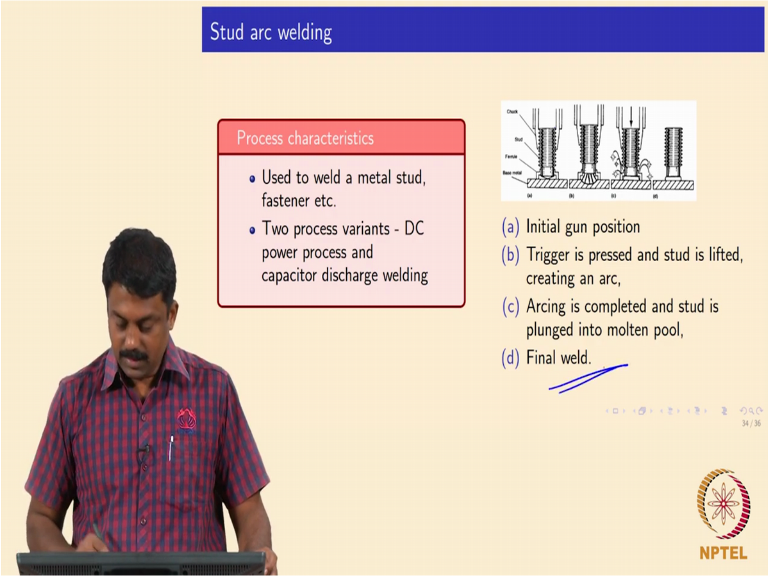
(Refer Slide Time: 17:41)




And some other characteristics of some other variants of friction, the solid-state welding process is high-frequency welding. And high frequency welding again I mean in compared to resistance seam welding, the temperature over here is much slower, okay. So, you just use in high-frequency welding the heating using an induction coil for only the sample and that induction coil heats up the edge and you have 2 roles that would join the interface by giving an upsetting force and you can make a continuous welded seam. Okay.

So, it is heated and then mechanically deformed, okay. And this process is ideal for making Seamless welding pipes and tubes. Okay, in this case, so you have only mechanical deformation, right and there is no real offsetting what you see in the resistance of that building. Heating can be kitted out by high-frequency induction of high-frequency resistance. Right, it is clear. Any questions? Yes or no? Okay. So, we will move onto the last but one of welding.

(Refer Slide Time: 19:00)



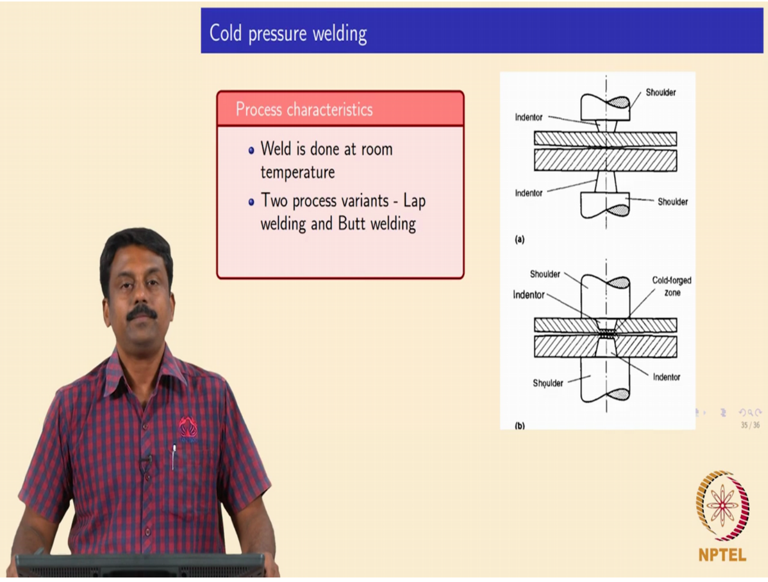

Stud arc welding. Okay, so this is again a solid-state welding process. And this is commonly used to weld fasteners onto the base plate, base material. Okay and especially in automotive industries, Stud arc welding is commonly used. You you have some sort of arc farming at the interface but the arc does not really do any melting, it will locally heat up the interface, okay. So, similar to the temperatures reached in solid-state welding process. So, you have wasted, gun, so you have a gun something like that, so with all the fasteners inside.

And you have hydraulic mechanism and a small, if it is needed, you can also have the current passing through the interfaces. So, here is a gun position and trigger is pressed, was the trigger is pressed and you have an arcing formed at the interface between the Stud and the base material and it heats up. And once the arc is completed and even upsetting, crossing the fastener to join to the base material. Okay. So, if you look at this process, and it is very commonly used in automotive industries.

And I do not know how many of you have opened the bonnet of a car and looked inside, okay. Even at the top rail, you must have seen the fasteners attached to the frame, the front grille, those are all done with Stud arc welding. So, the robotic arm carries these fasteners on hydraulics and then it also have connected to power source and then it will be, the robot would attach the fasteners in extremely fast time, something like AK-47 or so. So, it will continuously weld within no time, the fastener to the base material, okay.

So, it is used to weld metal stud or fasteners, nails for example, okay. So, you can either use it with DC power source conversely or we can also use capacitor discharge, okay, capacitor discharge is similar to what we have seen in previous classes. So, at the instant of the contact, it discharge large amount of current and locally it will form an arc and subsequently once heating is done, you offset the, cause enormous amount of pressure to offset the fastener into the base material. Okay. So this is very commonly used to weld metal stud, fasteners, nails, into the base surface. Good.

(Refer Slide Time: 21:45)

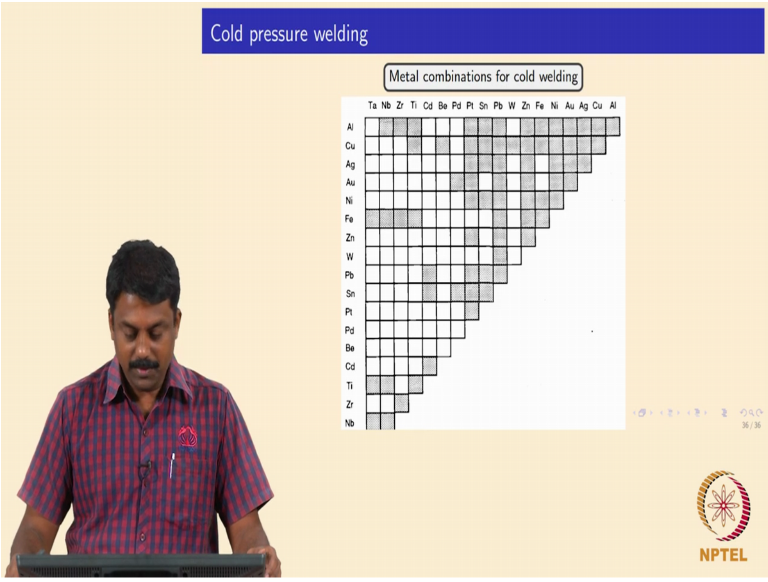



Then last, cold pressure building. So, welding is done in this case at room temperature, okay. So, what you need to use is you try to make the interface as flat as possible, okay and then you need to make sure that material at the interface can also classically deform, is not it, very soft material. For example you take lead, lead block, it is very famous, I am in very common you can observe, lead is really heavy. So, if you machine it, if you polish the lead surface and top it onto a table, you can never remove lead from the table, unless you melt it and take it out.

So, let is very notorious, because it deforms very easily, okay and if you polish the lead and drop it on the table, let is extremely heavy, okay, it is a heavy metal, right. And lead is very famous for making a cold joint with ready surface. So, lead blocks generally, you should not drop it, onto a flat surface, flat metal surface, okay, otherwise you cannot move, done, job done, okay, so you will have to melt. So the main important characteristic is the materials would flow classically at room temperature for a considerable amount.

The plastic deformation will happen at room temperature, so that at the interface mechanical deformation can take place while applying reasonable load. Is not it, okay. So, once you apply reasonable amount of load, you can cause the mechanical deformation at the interface, causing a joint made at the interface. Okay, so you can either do it lap configuration, overlap consideration or do butt configuration. So, you will have to apply loads perpendicular to the weld seam. Okay, in the transversal direction. Okay, good.

(Refer Slide Time: 23:52)




So, what are the combinations possible in cold welding, so the aluminium, aluminium can be welded, so with significantly with majority of materials because aluminium is soft, so it can deform at room temperature. So, the heavy materials is very difficult, so for example lead as I said can be welded with say led, and tin and titanium are commonly used, okay. And yeah, you can also prepare steel surfaces so smooth, you drop a steel block on a flat surface, it is very difficult to lift. It is not due to the lack of formation, it is due to the cold bonding you make at the interface. Yes, it is clear.