Manufacturing Processes – Casting and Joining
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Lecture – 16
Various Welding Processes

Hello and welcome to the course on Manufacturing Processes – Casting and Welding. Let me remind you that we started discussing welding and in my last two discussion sessions on welding we discussed about the basic principles, physics of welding process, how two parts can get welded, what is the physics behind the joining behind the coalescence of two metals.

And, we said that when the atoms are in equilibrium position where the attractive and the repulsive forces become equal, at that position we can be sure that the atoms will not be able to be displaced without a significant outer source or energy. It may be pressure; it may be a temperature and so on. And, we have seen in some of the welding processes that we need both temperature and pressure, and we will see some more processes as well.

We also started discussing on the residual stresses. I told you that the residual stresses may be dangerous for the engineering parts and the failure of the parts may be due to the residual stresses.

Residual stress may be one of the reasons in the failure of many of the engineering parts including the aviation industry parts which is most dangerous because it can cause the harm to many people. So, we have to be careful about the residual stresses. Similarly, in case of welding, residual stresses occur because of the temperature gradient.

The temperature gradient of the welded zone where the welding process has gone in, that tries to contract and that will be resisted by the base metal which will try to expand because of the heat that is being transferred or that is being conducted to the base metal from the welding zone. This contradiction will be there and because of that there will be a residual stress. I will draw your attention to this slide which we have shown last time.

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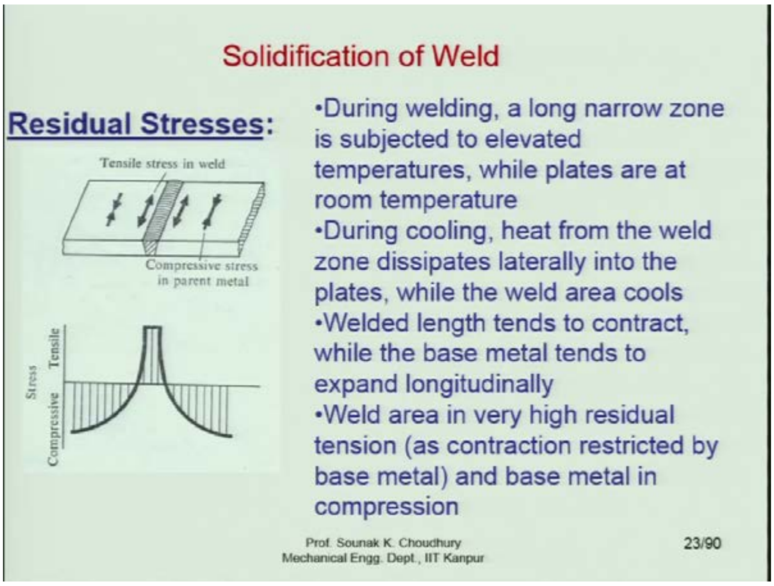

These are the two base metals, parent metal we say, and here this is the joint where the welding has gone in. In this part of the metal, the tensile stress will be in the weld and in the base metal there will be compressive stress. The curve will look like. This is the tensile, tensile will be in the welded zone and the compressive will be in the base metal.

So, during welding a narrow zone is subjected to elevated temperature where the welding has taken place while plates or the base metal will be at room temperature. During cooling this metal where the welding process has gone in, heat from the weld zone dissipates laterally into the plates. From here the heat will go into the plate while the weld area cools, that heat will go into the base plate.

Welded length tends to contract as we have seen in case of the casting for example, when the molten metal gets solidified. Here also welded length will tend to expand longitudinally because of that heat which is being dissipated to this base metal.

Weld area in very high residual tension as contraction restricted by the base metal and base metal is in compression. This is what happens when the welding has taken place in the cold base metal.

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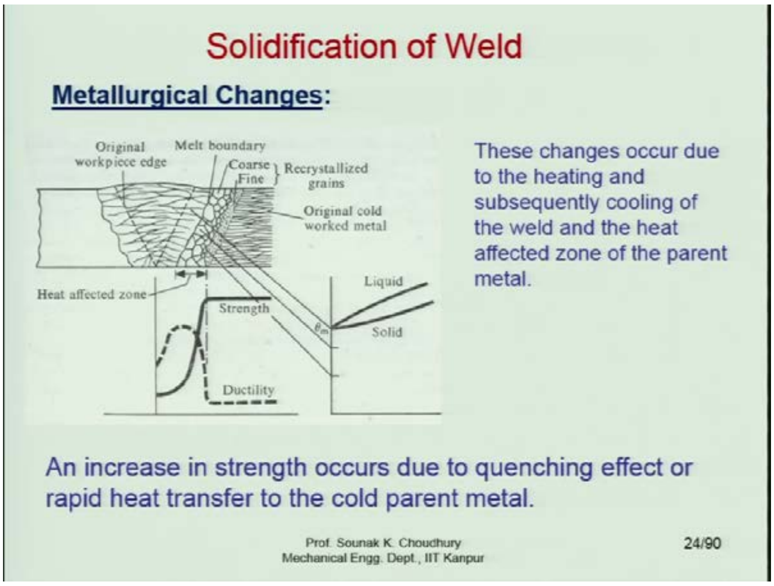

Because of this welding done, there will be a structural change and here it is in the exaggerated way the structures have been shown. Like, this is the original work piece edge, here we have the molten metal where the welding process has gone in and this is the melt boundary. Till this boundary around that the metal has been melted because of the welding.

Let us say this is fusion welding and this is the portion where the metal is not melted, but sufficient heat has gone in to change the structure of the metal. And I told you in my last discussion session that this is the heat affected zone; that is the zone which has been affected by the heat; heat which has been given for the welding process.

In the heat affected zone there will be two types of grains that we discussed also. There will be coarse grains and there will be finer grains. Finer grains are formed when the molten metal cools down rapidly.

Now, this heat affected zone. This is the portion which is adjacent to the base metal which is the original cold work metal. Here the heat affected zone will cool down rapidly. Therefore, in this part the grains will be relatively smaller, finer whereas, on the other side of the heat affected zone which is adjacent to the molten metal in the welded zone, it is different.

There the cooling time will be much more, or the cooling will be slower because it is adjacent to the hot portion of the metal. Therefore, the grains will be coarse grains. These coarse grains and the fine grains in the heat affected zone are the recrystallized grains.

The recrystallized grains or recrystallization takes take place when the grains change. They generate new grains that is why we call it as a recrystallization. Metal does not get deformed, but different types of grains are generated.

Here on the right side, you can see the original cold worked metal, and this is what happens actually. In this zone this is the point where we have the liquid and the solid liquidus and the solidus; we have discussed in casting while discussing the pure metal and the alloy metals. This is the point where we have the molten metal.

Here we have the metal which is adjacent to the molten metal and this belongs to this portion and this is colder. Therefore, it is actually below, and this is what happens in the heat affected zone. Within the heat affected zone, the ductility increases as it goes towards this side ductility becomes maximum and then it falls because of the temperature change or the gradient here.

As far as the strength is concerned right from here the strength starts increasing, and it goes up to this where we have the finer grains. After that the strength does not change because that will be the strength of the original cold work metal, that is the base metal which you have seen and therefore, the strength will be of the base metal.

But, otherwise from the molten metal the strength will keep increasing up to the boundary level of the heat affected zone and after that it gets straighten up. These changes occur due to the heating and the subsequently cooling of the weld and the heat affected zone of the parent metal. This is what happens overall during the welding process.

An increase in strength occurs due to quenching effect. Quenching effect happens because it is cooling down. Cooling down rapidly because, it is in contact with the original cold work metal now; or rapid heat transfer to the cold parent metal.

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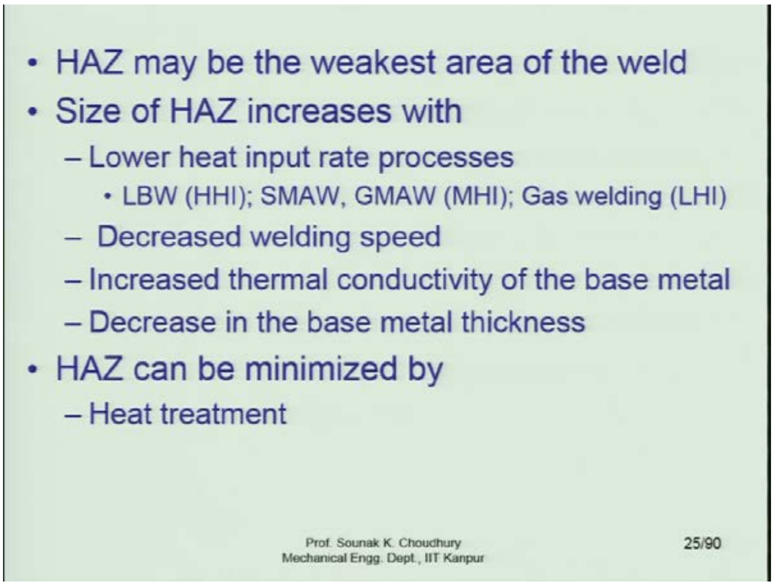

Heat affected zone may be the weakest area of the weld. This I also said earlier that when the metal welded zone fails, it can fail along the heat affected zone. Size of heat affected zone increases with lower heat input rate processes. Like for example, laser beam welding or SMAW. These are the processes that will be discussing later. Gas welding: here the heat input is lower, at a lower rate. Whenever the heat input is at a lower rate, the size of the HAZ will be less.

Decreased welding speed for example, if the welding speed is less that will affect the heat affected zone. Increased thermal conductivity of the base metal; decrease in the base metal thickness. So, you can easily realize now what happens to the heat affected zone if we decrease the base metal thickness.

Heat affected zone (HAZ) can be minimized by the heat treatment. When we are performing the heat treatment, to a large extent the heat affected zone will be neutralized or it can be minimized.

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Various welding processes: solid - state welding; in many places it is also called the solid phase welding. In solid state welding the liquid phase is not present, as the name itself says that it is the solid-state welding or solid phase welding, and phase is only the solid.

There is no liquid phase. The high temperature promotes bonding in the case of the solid-state welding. Pressure promotes bonding by plastic deformation. Here since there is no melting or there is no liquid state, it is only the solid-state welding.

Therefore, here we will have both temperature and pressure or one of them, but this is very high temperature or high pressure promotes the bonding by the plastic deformation.

High pressure because it will be able to create the plastic deformation because bonding has to be through the plastic deformation. Does not require consumable electrodes, which is advantageous here. Shielding gases or flux that we require in the liquid state welding are not required here.

These are the advantages of the solid-state welding. However, in the case of solid state welding the temperature has to be very high, the pressure has to be higher for creating the plastic deformation and so on. So, there are certain advantages and disadvantages that we will see at a later stage.

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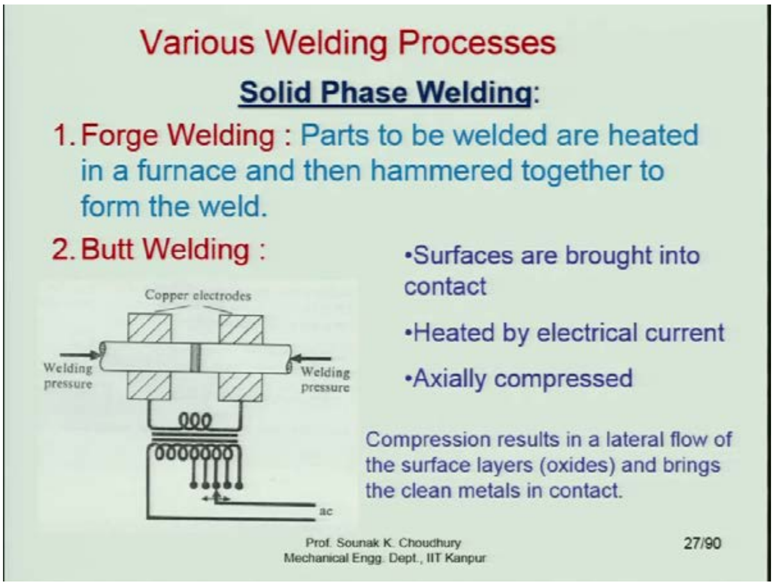

Forged welding is one of the solid phase welding processes. The name itself says that it is forged by pressure. You know how forging in the metal forming process is done. The parts to be welded are heated in a furnace and then hammered together to form the weld. Very classic example and very old example is the forge welding of the rim of the bullock cart, which is still being used in many villages and suburban areas.

The bullock cart has a wooden wheel. To protect that wooden wheel from getting worn out very fast there is a rim all around the periphery of that bullock cart wheel, there is a metal rim. That metal rim has to be joined together and if you have seen that it is being done manually; it is heated up and when it is red hot, those two ends are fixed and then hammered. This is simply forging, and they are welded. Those two ends are welded and that is called the forge welding.

Here it is solid state welding because the temperature goes very high and then it is by hammering or by the impact pressure the two ends are welded or it can be butt welding. The butt welding, the name itself says that the joining will be along the butts.

Surfaces are brought into contact. Heated by electrical current; here between these two electrodes an electric current is passed. In normal cases these electrodes are copper electrodes because the electrical conductivity of the copper is very high. So, the heat is generated as the current is passed between them.

This is the electric coil and after the joint is heated up, it is axially compressed. There is a pressure given from both sides and it is in this place of contact where these two parts are joined. The compression results in the lateral flow of the surface layers.

As you understand that on this surface particularly when it is heated up there will be oxides because of the oxygen from the air and those oxide layers will create hindrance in joining them together.

When there will be a lateral pressure, the material will flow laterally and the oxide layer which is on the surface will be removed and the nascent material will be joined together. Once again, the compression due to pressure from both sides results in a lateral flow of the surface oxide layers.

As the welding pressure is exerted on these two, the lateral flow of the material will take place and that material is the oxide layer and that brings the clean metal in contact and they will be joined. After some time, this pressure is withdrawn, this is stopped, and the welded parts are taken out.

These are the clamps to hold the work and the copper electrode together. Different kind of setups are there. This is the schematic diagram which shows that through these electrodes the current is passed, and the heat is generated here.

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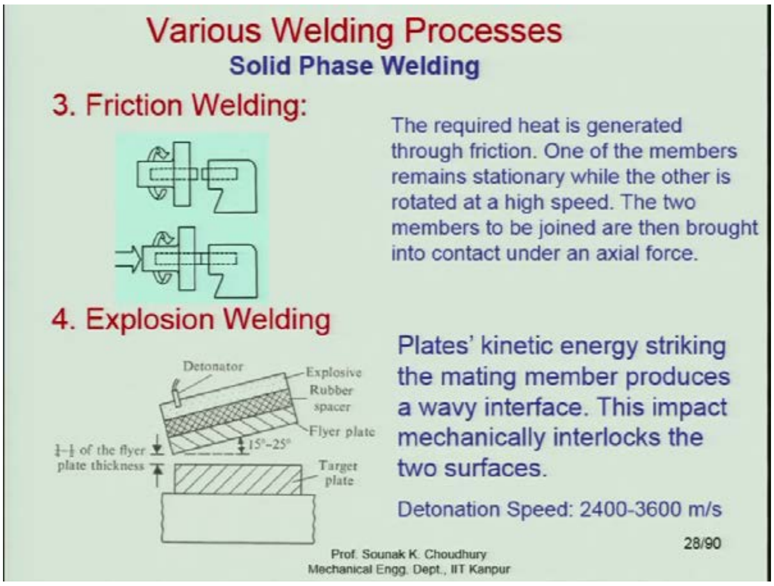

Other solid phase welding or solid-state welding: this is another one which is called the friction welding and of course, the name itself says that there is friction involved and because of the friction the heat is generated.

Here the parts are shown in dotted line, protruding out from the chucks. This much is protruding out of this part which is not shown completely. This is the non-movable side of the part and this part is clamped in a jaw chuck and this rotates.

When they are in contact with each other, because of the rotation of this part, there will be friction and because of the friction the heat will be generated. The oxide level will be removed to expose nascent surfaces, the clean metal will be in contact and the two parts will be welded at this joint.

The required heat is generated through the friction. One of the members remains stationary as I said while the other is rotated at a high speed. The two members to be joined are then brought into contact under the axial load. This axial load will remove the oxide layer also and the fresh metal will be revealed and that will help in joining these two parts. This is the friction welding.

Friction welding is also very popularly used in practice for many parts because as you understand that here it is only high speed rotation involved where because of the friction the heat is generated.

Another example is the explosion welding and here also the name itself says that there is an explosion created through the explosives. Because of that explosion, the pressure that is being created will weld the two surfaces. here is the setup, shown as a schematic diagram.

These are the two parts to be joined. This is called the flyer plate, and this is the target plate. On the target plate, which is on the anvil, this flyer plate has to be joined along this surface. On top of this flyer plate there is a spacer rubber spacer. Rubber spacer is given for damping the vibration, damping the impact and here the explosive is kept.

There is a detonator. When the detonator will be fired, the explosive will react and that will create the explosion. Now, between them there is a gap of about one fourth to half inch of the flyer plate thickness and the flyer plate is kept at an angle of around 15 to 25 degrees as shown in the diagram.

Kinetic energy of the plates striking the mating surfaces produces a wavy interface because it happens at a very high speed. When the explosion takes place, this flyer plate will hit the target plate at a very high speed.

And, because of that there will be a wavy interface and this impact mechanically interlocks those two surfaces because both the surfaces of the flyer plate and this surface of the target plate will have those wavy interfaces which can be locked because of the very high pressure created by the explosion.

The detonation speed is very high which may be up to 3600 m/s and 3600 m/s is a very high speed . So, at that speed the flyer plate will be hitting the target plate and the kinetic energy will be very high because of that.

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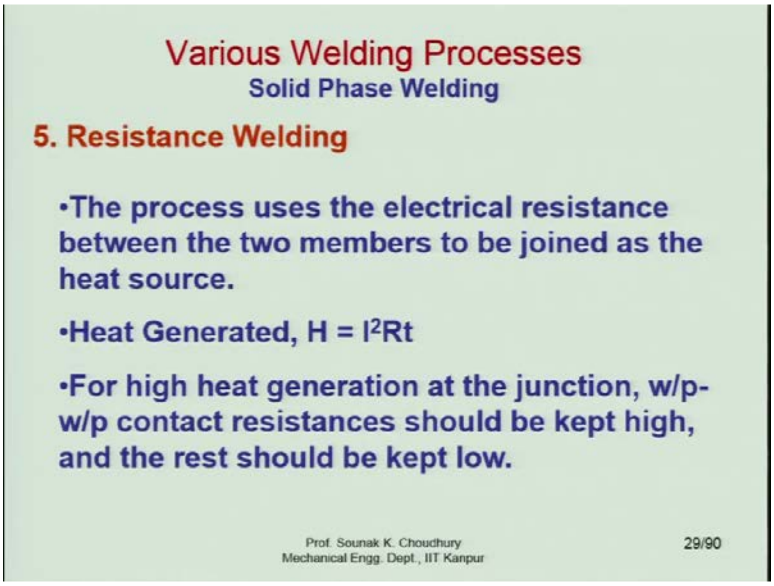

Resistance welding is another one. The process uses the electric resistance between the two members to be joined as the heat source and the heat generated is given by this formula. The heat generated *H* is equal to $H = I^2 Rt$; *R* is the resistance, and *t* is the time it is the duration through which the current, *I* is passing through the resistance.

If we have a circuit where the *I* is known, resistance is known and the current is passed through the circuit and we will be recording that timing, i.e. for how long the current is flown, then we can find out the amount of heat generated. So, you can find out exactly how much heat is being generated by that circuit.

For high heat generation at the junction, work piece-work piece contact resistance should be kept high because higher the resistance higher the heat.

H is directly proportional to the resistance, directly proportional to the time and the resistance of other contacts should be kept low.

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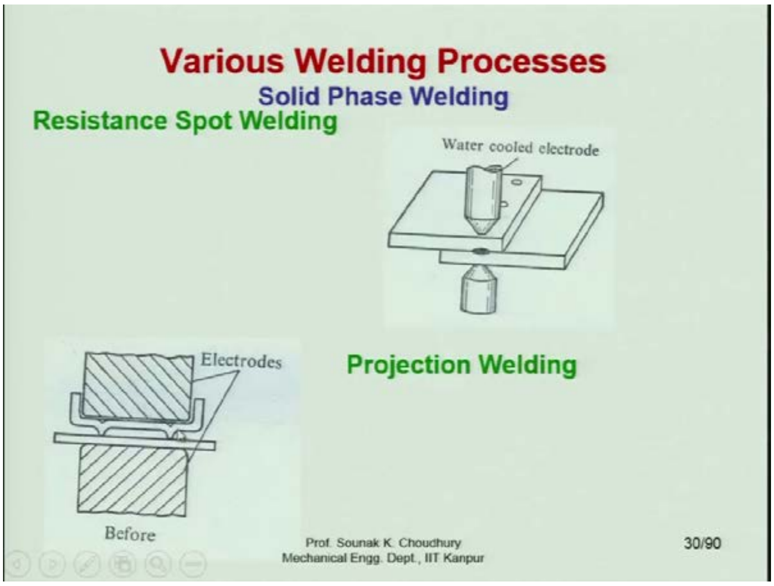

Let us see how it is maintained. If you see the diagram, this is the resistance spot welding. Here, work piece to work piece contact is more. So, the resistance is more. Other contacts will be of the contact of the electrodes. Here is one electrode at the top and another electrode is at the bottom.

Here the surface area of the electrodes is minimized so that the contact could be minimum, and the resistance could be less because we want the heat to be generated at the contact between the workpieces. If we get the high surface area between the electrodes and the workpieces, then this will also be heated up and that will be waste, and the welding process cannot be performed.

These electrodes get heated up in the process, because passing of the current through the electrodes and heating up the plates also heats up the electrodes. Therefore, these electrodes are cooled down by the cold water circulation. Another type of the resistance welding where the same principle is used is called the projection welding.

Here also the same principle is applied that the two electrodes are here in this and here we have the projections made so that the heat can be generated along the projections and not along the entire surface. These two places will be welded, and we want that these two parts to be joined at these two points.

Then such kind of a projection can be made, and it is called the projection welding. This is also required in many places in practice.

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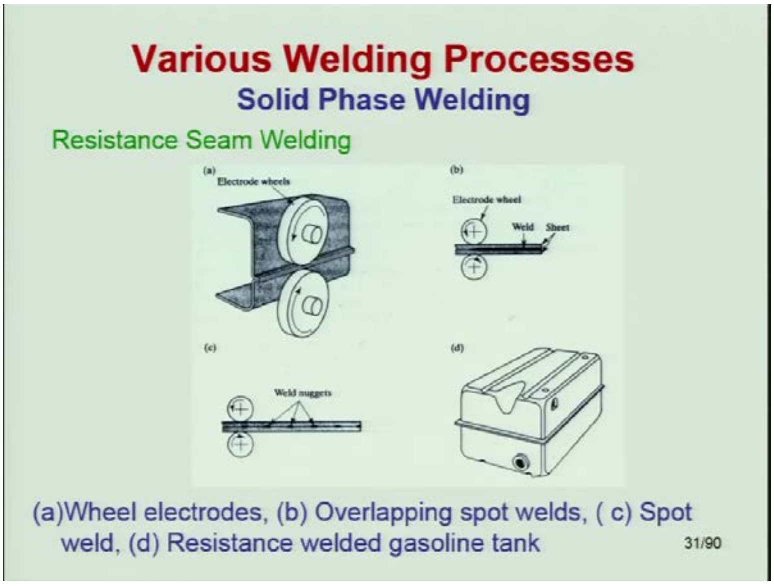

This is another process which is called the resistance seam welding. Here, there are wheels, and these are the plates, and as you can see that there is a seam here from this plate and from this plate. these two seams are to be joined. It is shown here for example, these are the two sheets like seams if you see from this side.

These two wheels are rotating, and these are also the electrode wheels and the material will be welded along the seam because it is travelling from one place to another place and here you will be welding nuggets. Through the welding nuggets they can be welded because at these points only the electricity will be passed. Therefore, they will be welded at these nuggets.

Wheel electrodes are also used in overlapping spot welds as shown in the figure (b). This is the example of the spot welding at different spots. This is similar to the one that we have shown for projection welding. We make small projections here and there will be welding at the nuggets. Here this is what is shown is a resistance welded gasoline tank.

This is the entire setup that is required for making that welding. So, as you can see that it can be taken out and it does not need to be performed in a closed area or in a particular area or in the factory site. It can be performed in the open area. That is another advantage of the process. Rest of the material we will discuss in our next discussion session.

Thank you very much.