**Basics of Mechanical Engineering-2**


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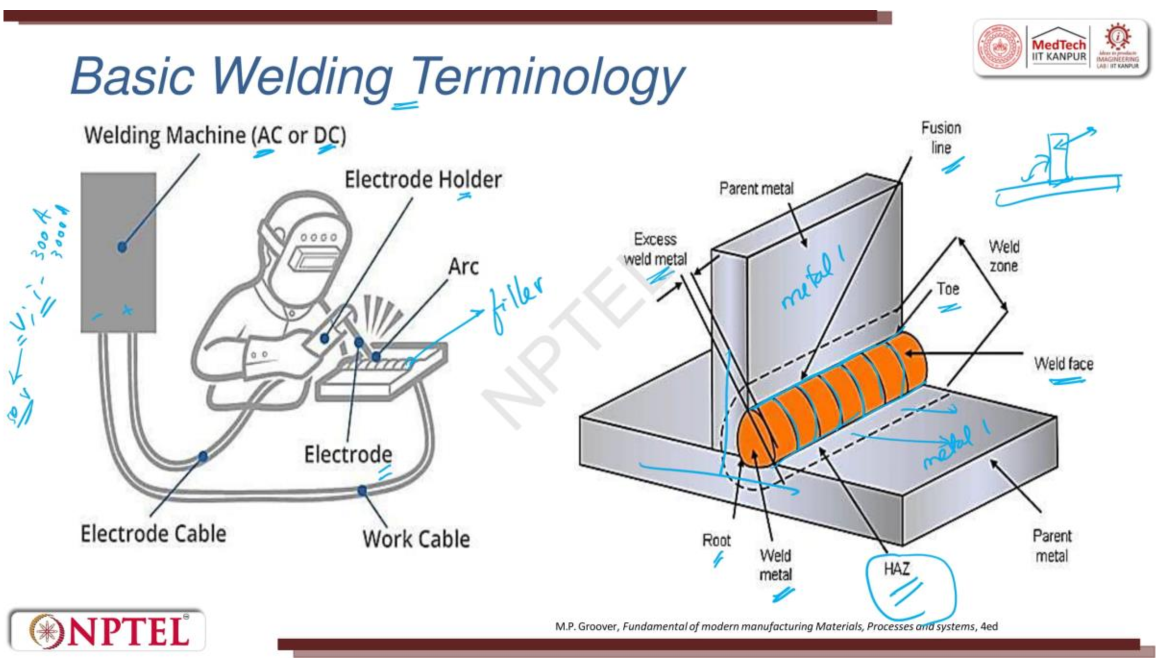
**Week 07**

**Lecture 25**

**Basics of Welding (Part 2 of 7)**

Welcome to the topic in this course: welding. Welding is a very important topic in manufacturing.




So, when we look into basic welding terminology, you will always have a welding machine, which is nothing but a power source. The power source can be AC or DC. Until now, we were happily using DC, but there is always a conversion factor from AC to DC where there is a tremendous loss.

So now, there is a lot of research that has gone into this, and now we are trying to use AC as the power source itself—alternating current. From the power source, we have two electrodes which go. One gets connected to the workpiece, right. And the other one gets connected to the electrode which is held by the person. So, the electrode holder will be connected with the other cable.

So, one can be negative, one can be positive, whatever, depending upon the requirement. So, it gets connected here, it gets connected here. So, there is an arc, the circuit is closed. So, there is melting and then material gets flown. So, it moves through a cable, and here generally what happens is we try to have voltage and current.

The current values are high. The current values means I am talking about it can go up to 300 amps, 3000 amps can go very high. So correspondingly the voltage what happens it is very low. So we will try to operate at maybe 50 volts, 100 volts, 150 volts etc. So voltage current combination is used here and then we start applying.

So when we try to melt material and flow, this is called as the filler, which is melting and flowing it inside. So this, if you zoom it out, you will see something like this. So here it is a flat plate, but here we are trying to demonstrate a T-joint. This is a metal plate. This can be metal 1 or metal 2, whatever it is.

So, when we have these two perpendicular you are holding. Now these are free, now you are trying to hold it and now you are trying to join. When you are trying to join, there is a filler material which is flown. Which tries to join metal 1 and metal 2 or flat plate and a perpendicular plate. So, you can see here there is a fusion line.

This is a fusion line between the parent metal and the weld phase. This is a weld phase; this is a metal. So, between these two, there is a fusion line. So, you have a fusion line here, and there is a fusion line here also. The fusion line is where there is a gradient shift between the material that melts and flows and the cold metal.

So, this is the weld metal; the orange one is the weld metal, which is filled here and then joined. So, when we try to do it, if you have exactly a flat plate like this. There is a possibility that this can shift this way or it can go like this. So, what we do is we try to create a small slot for holding. So, that is called a root.

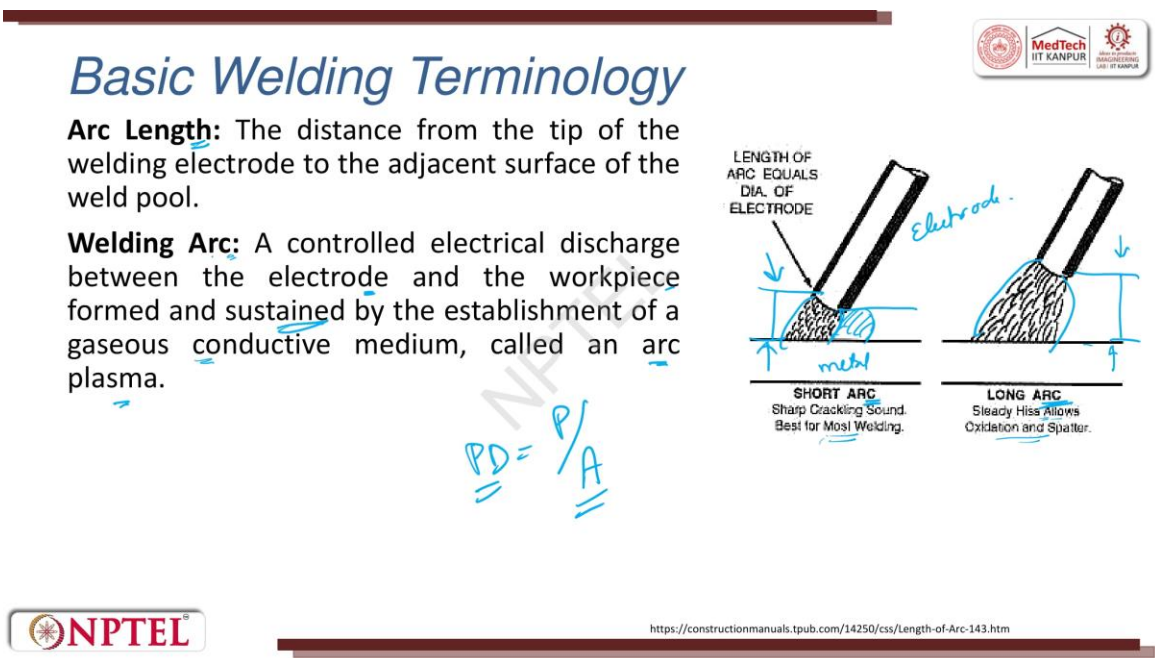
So, the root is where the weld will flow and then form a bead, which will try to join. So, when this metal is heated and flows and then joins, there is always heat dissipation that happens. The heat gets conducted, and the heat moves along the parent material. So, till where do we see the heat? That is called the heat-affected zone.

So, weld zone until the heat dissipates. From the weld to the weld zone, what we have is called the heat-affected zone, HAZ, HAZ, right? And then we try to have the pattern in which it is flowing. This is also very important. So, we have a toe.

The toe is at this portion, right. So now I have explained everything. So, excess weld metal—what happens is when we start exactly dot to dot. We cannot start perpendicular when we see from the side. So we start slightly earlier and then melt.

So that is called excess metal welding. So, two metals perpendicular to each other are joined. So you have a weld which flows there, and then you try to join. So you see the heat-affected zone, which is very, very important because there is a microstructural change. After that, it becomes normal.

So when we try to talk about the electrode which is there, is the electrode touching? Is the electrode very far off, or is it very close? So that makes it very important because there is a melt of material and flowing.




So there is something called arc length. So this is the electrode, and this is the metal, whatever is the base metal. So here, if you see, the distance is called arc length. It can be short; it can be long. When it is short, it creates a sharp cracking sound. It is best for most welding processes with a shorter length. When it is far off, it produces a steady haze, allows oxidation and spatter to happen or seal.

So this arc length tries to affect or plays an important role in the power. So if you see here, power density is nothing but power by area. So here the area is large; here the area is small. So the power density for a short arc will be high. So the moment it is high, melting and falling can be done very fast, and heating at this zone.

Suppose if there is a mixing have to happen, that also can happen. So arc length is one of the most important parameter how do you set. The distance from the tip of the weld electrode to the adjacent surface of the weld pool is defined as the arc length. Welding arc is a controlled electric discharge between the electrode. And the workpiece formed and sustained by the establishment of a gaseous conducting media called the arc plasma is there.

So the arc, whatever is there, it is continuous in nature. Because when you try to initiate an arc, now you have to sustain the arc all throughout the length. So weld arc is very, very important. It is controlled electric discharge between the two electrodes. Electrode is electrode and the workpiece, which is formed and established by, formed and sustained.

So, this is what is the difference between arc and a spark. Arc is sustained, spark is discrete, right, formed and sustained by the establishment of a gaseous conducting medium called as arc plasma. So, this is what we are talking about. So, once this happens, the arc length happens and the welding arc happens. Then what will happen is this portion where the melt and everything is there will be exposed to atmosphere.

When it is exposed to the atmosphere, it can react with the gases in the atmosphere. So, now basically what you are supposed to do is shield them. The melting zone has to be shielded.

## Basic Welding Terminology

**Flux:** Welding flux is applied to remove oxides and contaminants, improve wetting, affect the final surface profile, and may also influence the weld metal's chemical composition.

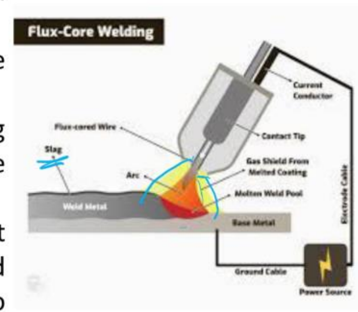
**Shielding Gas:** A gas used to produce a protective atmosphere.

**Welding Flux (SAW):** A granular material applied during welding to shield, clean the molten weld metal, influence the weld profile, and affect the weld metal composition.

**Duty Cycle:** The percentage of time during a specified test period that a power source or its accessories can be operated at rated output without overheating (Ratio of Arc ontime to idle time ).

**Welder:** One who performs manual or semiautomatic welding.

duty cycle = $\frac{t_{on}}{t_{on}+t_{off}}$




https://weldguru.com/what-is-flux-in-welding

So what we do is we try to introduce a compound called flux. Welding flux is applied to remove oxides and contamination, improve wettability, and affect the final surface profile.

It may also influence the weld metal's chemical composition. So either you protect it externally, Or what you do is you try to have reactions in the melt itself such that all the unwanted elements are moved to the top. Both can be done. Welding flux is applied to remove oxides and contaminants that are formed while the reaction and melting occur.

It also tries to improve wettability or wetting. What is wetting here? When the metal tries to flow on top of another metal, there is a phase change from solid to liquid. Or an X metal or a Y metal. So there is a difference.

So now when there is a difference, then there is a surface phenomena which plays very important. This surface phenomena has to be removed and the metal has to uniformly spread. So that is called as wetting. So wetting also improves. Say when you are trying to give a butter coat on top of a tawa or something.

So that is basically to make sure that wetting of the surface is improved. So improves wetting and which affects the final surface profile. It also influences the metal composition. So that is flex. The flux can also be used as a shielding.

But if you want, you can have a separate shielding gas. So along with the flow of molten metal which gets coming. You can also have a shielded gas which tries to flow around it, protected from getting reacted with the atmosphere. Both are possible. But flux is different, shielding gas is different.

So, here if you see flux core welding, you see once the welding is done, it forms on the top whatever is there, it forms the slag. The slag is nothing but the oxide which is on the top, which can be chiseled off or removed once the welding is done. Welding flux, a granular material applied during welding to shield and clean the molten weld metal, influences the weld profile. And affects the weld metal composition. So, that is weld flux. OK, the next important parameter will be the duty cycle.

What should be the amount of time the arc should happen? And how should you go? That is always defined as a duty cycle, the percentage of time during a specific test period. That a power source or its accessory can be operated at rated output without overheating is called the duty cycle. Basically, the duty cycle is defined as T_on divided by T_on plus T_off. Time on divided by time on plus time off.

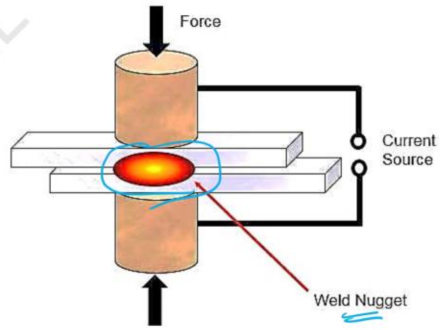
So, the percentage of time during a specified test period. That a power source or its accessories can be operated at rated output without overheating is called the duty cycle. It is the ratio of arc-on time to idle time, which is what I said the duty cycle is. So, this is also very important. So, and then finally, the skill of an operator.

So, what are all the important things? First, the arc length has to be maintained, then the welding arc has to be maintained. Then, the arc length has to be maintained, flux is to be added, and shielding gas is to be added. And the voltage and current you apply have to be linked with the duty cycle. So, when we control the duty cycle, you will try to get the best welding output.

## Basic Welding Terminology

**Welding Electrode:** A component of the welding circuit through which current is conducted and that terminates at the arc, molten conductive slag, or base metal.

**Weld nugget:** It is the melted area formed during welding, crucial for creating a strong bond.



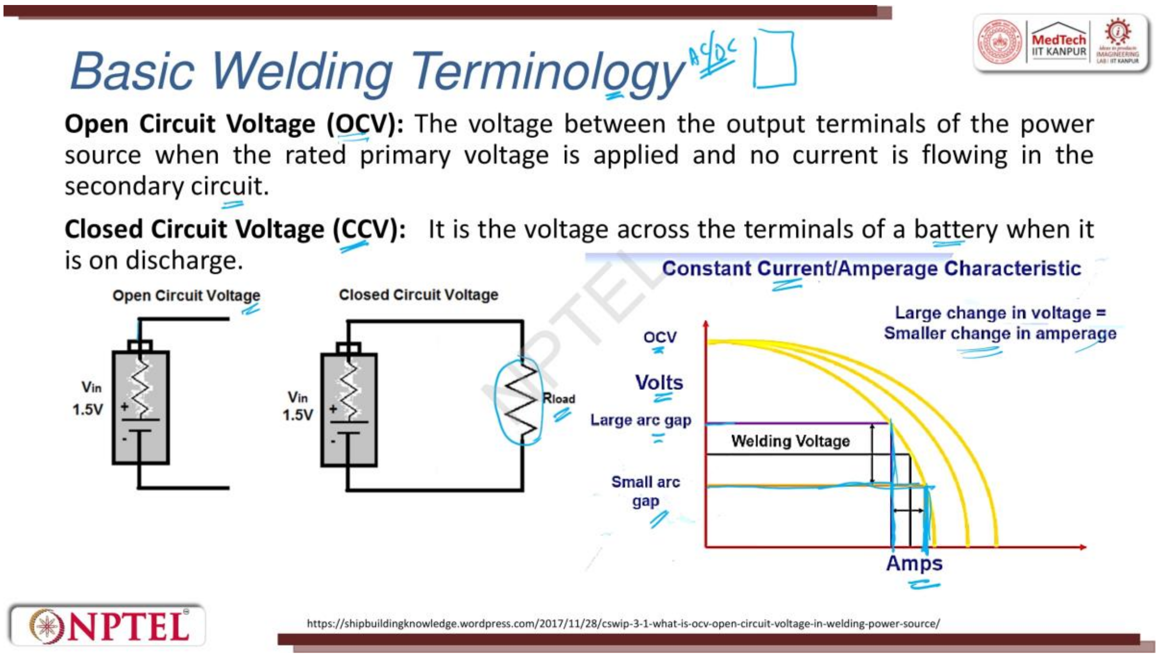

https://www.marineinsight.com/guidelines/a-guide-to-welding-electrodes-on-ships-part-1/
https://ims.evidentscientific.com/en/applications/spot-weld-testing

So, to do this, we will always try to have an electrode. The electrode, which is there, is a component of the welding circuit. Through which the current is conducted, and that terminates at the arc. The molten conductive slag or the base metal. This is an electrode; the circuit is attached here.

And then, on top of a workpiece, you try to create an arc, melting the electrode. This is an electrode; it will melt and then fall. So, what is the color on top of it? These colors are powders coated on top of the electrode, which act like a flux. And sometimes, it reacts with the metal there and also forms a gas.

The nugget is the portion, this is the nugget, the melted area formed during welding. It is a crucial factor for creating a strong bond and is called a weld nugget, okay? So, the weld nugget here is formed by resistance welding. And force is applied, or just for understanding what a nugget is, I am explaining it. So, you should clearly know the nugget.

And then here we have talked about the heat-affected zone, weld metal, and heat-affected zone. Please keep that in mind; these are all different.




We have to talk about the source, right? We said it can be an AC source or a DC source. So, there are two terminologies that are very important in the power supply. One is called the open-circuit voltage (OCV).

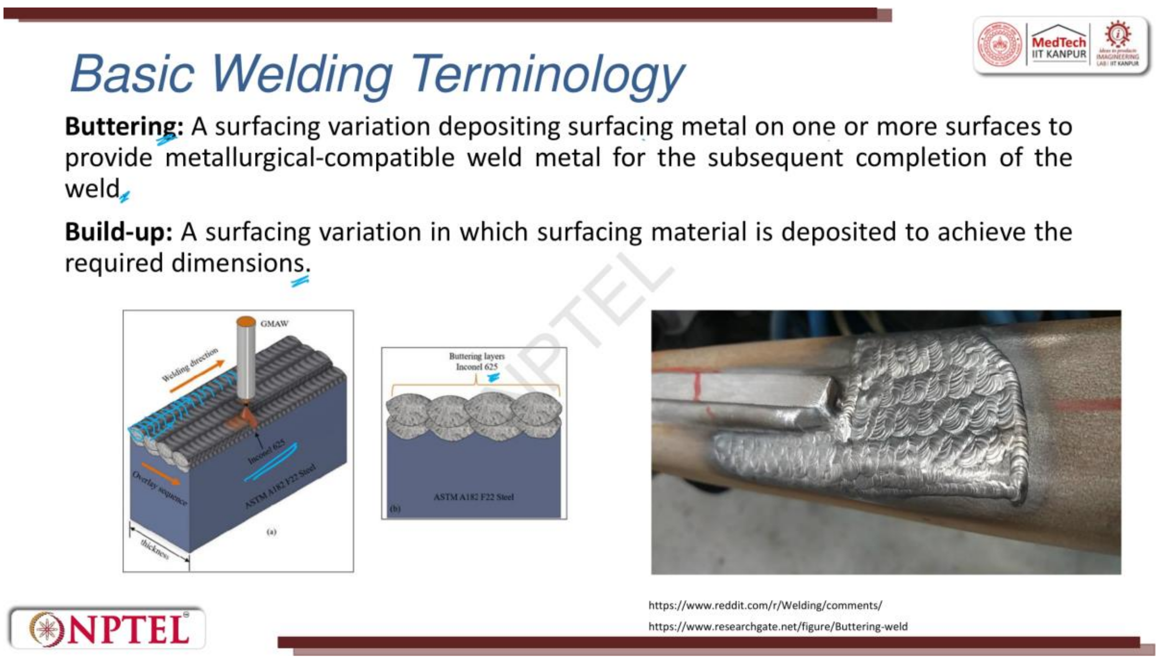
The other one is called the closed-circuit voltage (OCV). OCV is the voltage between the output terminals of the power source. When the rated primary voltage is applied and no current is flowing in the secondary circuit, it is called OCC. So, when the primary is applied and no current is flowing through the secondary circuit, it is called OCC. The OCC circuit looks like this.

So when we talk about the source, we try to talk about open-circuit voltage and closed-circuit voltage. In the closed-circuit voltage, it is the voltage across the terminal of your battery when it is on discharge. So I have taken a battery as an example, but here you can see this is an open circuit for a battery. That is why I have taken an example of a battery. So you have your load where the arc happens and the welding happens.

So that is called the closed-circuit voltage. So you can have a constant current mode or you can also have a constant voltage mode. So an OCV curve is plotted like this, voltage against time. So you can see these are the different types of curves which are there. If you have a larger gap, you see the voltage is high.

When you have a smaller gap, the voltage is low, right? So when you see the influence, the influence of current you can see here it falls here and the open large-gap current falls here. So for any difference in voltage or for a large difference in voltage, there is a small difference in current. So in a large gap, the current is small, right? The ampere, whatever we set, is small when we take a small one; it is large.

So, a large change in voltage equals a small change in current. So, this is for constant current amperage characteristics. It is done like this. So today, what has happened is you set the voltage and bring the electrode closer. Now, it is automatically adjusting the gap in the arc length so that you get the best out of it. So, you are supposed to understand the open circuit voltage and the closed circuit voltage.

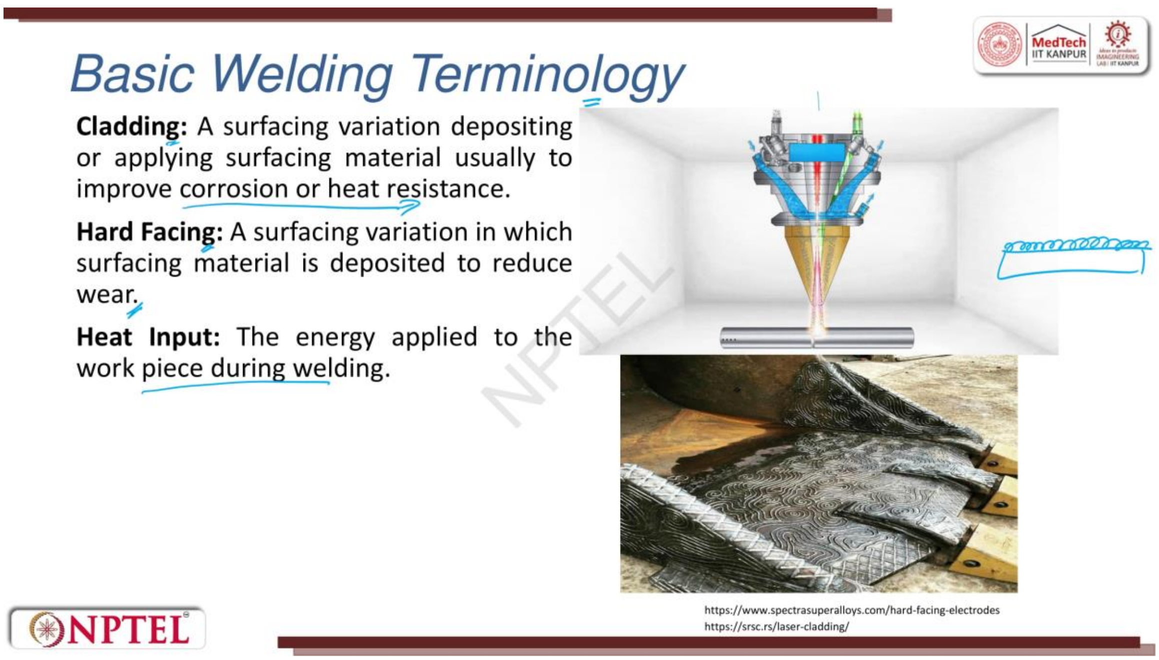



The other phenomena are going to be buttering, a surfacing variation, depositing surfacing metal on one or more surfaces. To provide metallurgical compatibility, weld metal for the subsequent completion of the weld. So, basically, buttering means you try to coat a surface, a surfacing variation, depositing surfacing metal on one or more surfaces to provide metallurgical compatibility. For example, metal A, you have metal B going to sit between these two; there is a variation.

Now, you give a buttering on top of it. A surface variation, depositing surface metal on one or more surfaces. To provide metallurgically compatible weld metal for the subsequent completion of the weld is called buttering. So, if you go back, it is like wetting, right? Then, built-up is a surfacing variation in which surfacing metal is deposited to achieve the required dimension. So, you can see here a buttering layer is formed in Inconel 625.

So, you can see here there is a welding electrode which goes on top of Inconel 625. So here, if you see, you will have this as one layer. This is one layer.

So, between two layers, there is something called an overlap. And in one layer itself, you will have an overlap again. So, this ensures that you will have proper welding. So, this is the overlapping sequence, and this is the weld direction. So, if you see, the buttering layer is on top of Inconel 625.

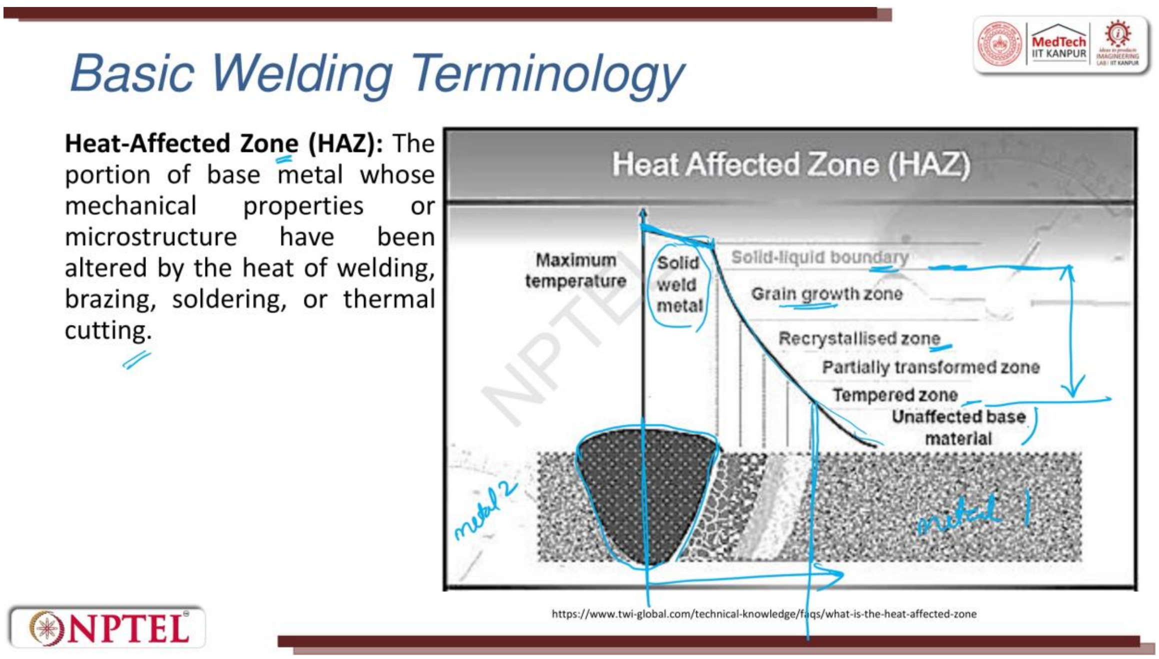



So, cladding is also another process which falls under welding. So, since we were talking about buttering and buildup, now, from there, we can also move towards a small variation in the welding process, which is cladding. So, why only wire or rod should be used? Can't I use a powder?

Yes, you can use a powder, but the only thing is you can't deposit it in a short confined place having a high aspect ratio. But still powder also can be used. Once the powder is used and then heat is applied, we call the process as cladding. A surface variation depositing or applying surfacing material usually to improve the corrosion or heat resistance is called as cladding. Heat wire is replaced, rod is replaced by powder, it is called as cladding.

The cladding always leads to hard facing, a surfacing variation in which the surfacing material is deposited to reduce the wear. So, you can try to have a metal, then you can try to have some powder deposited on top. This will try to improve the wear resistance. That is what is cladding. We also saw cladding in forging process where a sheet, complete sheet will be cladded with other sheet joining.

That is cladding. So, here it is powder cladding. So you can do by plasma, again oxyacetylene can be used, you can try all these things or explosion also can be thought.




The heat input, the energy applied to the workpiece during welding is the heat input. This is what is we were trying to discuss in brief in the beginning of this lecture, heat affected zone.

So if we try to take a cross section, this is the weld zone material which is deposited or welded. So, you have metal 1 and metal 2, two different materials. So now there is a welding material port, and the welding happens. So here there will be a lot of heat. When we try to take the cross-section area, you can see at the middle portion there will be maximum temperature.

As and when you move along the axis, you will see that there is a profile of heat. The temperature drops down with respect to the distance we move. Of course, time is also there. But here we have finished the welding operation. We are trying to take a cross-section and then we are looking at it under the microscope.

You can see here the temperature distribution. How can you see the temperature distribution? The temperature distribution can be seen by the microstructural changes. So here, the solid welded metal is seen up to this portion. So while the welding process is going on.

You can see the temperature falls down here in a linear fashion to a small extent until the weld portion is present. The moment the weld portion is over, the metal starts forming an interface, which is the fusion line I mentioned. So you will have a solid, then you will have a solid-liquid boundary. Now, close the discussion here and move to casting. In casting, you pour the liquid metal inside a mold, and at the mold walls, you have a thermal gradient.

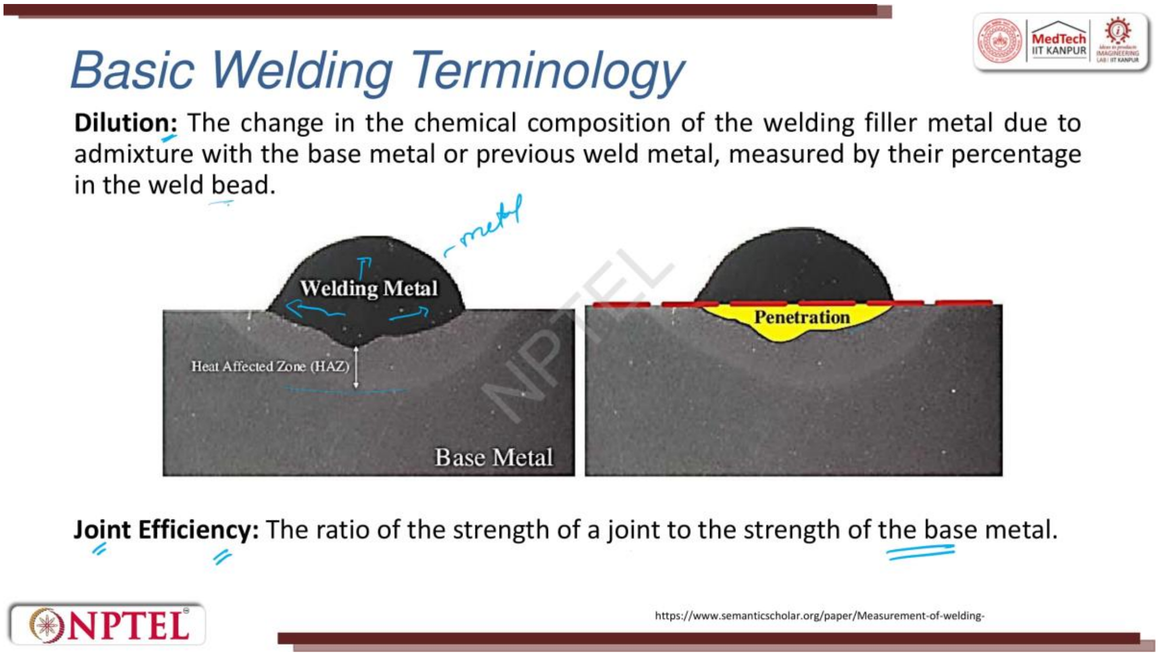
So there is a change. So that's what is called a solid-liquid boundary, as you studied there. And there, you also studied about the grain growth zone. So the grain tries to grow along or against the heat, forming grains. So there is a growth of grains which happens.

Then, as this continues, the heat persists. Then there is grain growth. So then you will also see a recrystallization zone. So melt, grain growth happening. Then you see recrystallization happening because the temperature is falling.

So, if you try to take a metal in the heat treatment we saw, before getting into melt, we saw a recrystallization zone. So, recrystallization, then partial transformation, then you will have a tempered zone, then you will see an unaffected zone. So, between the grain growth zone, between the grain zone and the tempering zone. You see there is a steep fall in temperature, a steep fall in hardness also, right. So, the heat-affected zone will have up to here, up to here will be the heat-affected zone.

Or you can even travel a little bit more and go into the unaffected base material. The heat-affected zone, the portion of the base metal, whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, or thermal cutting. So, it is called the heat-affected zone. So, friends, the heat-affected zone plays a very important role in terms of mechanical properties.

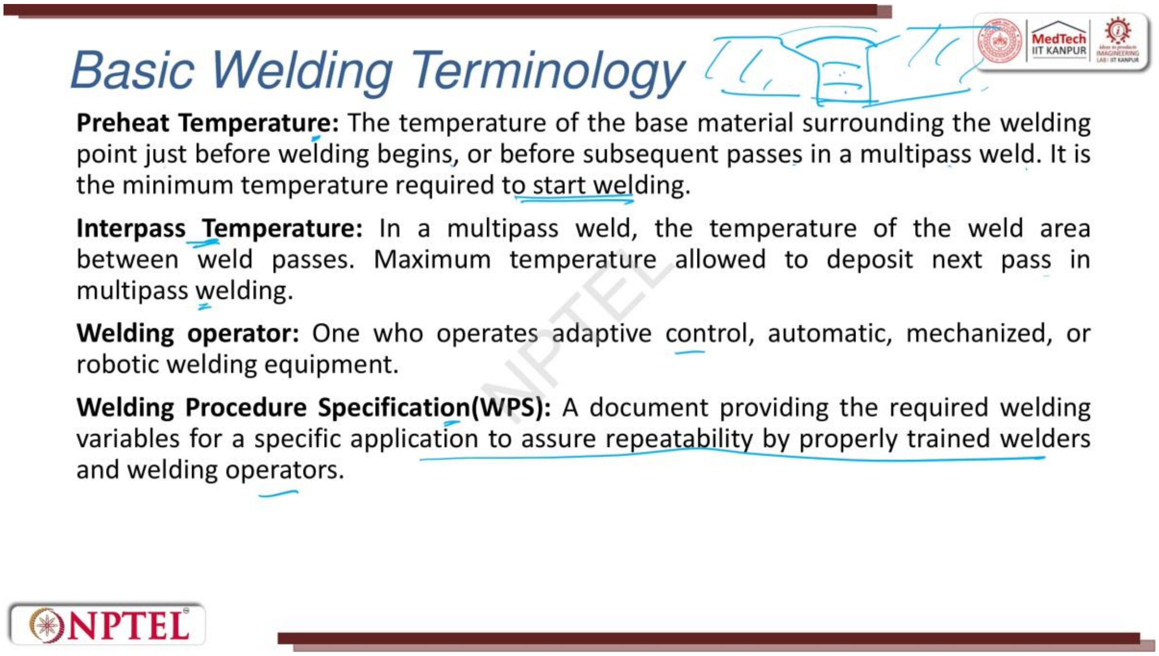
So, when the melt flows, it is very important to flow properly. See, because it is a metal, the viscosity will be very high. So, you have to make sure that it flows. So, for that only, we add some flux and other things.




Dilution is a very important phenomenon. The change in the chemical composition of the welding filler material. Due to the addition of a mixture with the base metal or previously welded metal, measured by their percentage in the weld bead, is dilution. So, what we are trying to say is when the metal is present. If you try to change the viscosity such that it can flow easily into the undulated zone and then join. So that is dilution.

In the eye, we also do dilution. That is dilation; this is dilution. So here, you see weld metal, heat-affected zone, you can see here. And then you can see how the weld metal penetrates into the base metal. Joining efficiency is the ratio of the strength of the joint to the strength of the base material, which talks about the efficiency of the process.

This portion, joining and the base metal, you know, the base metal joining. So the strength between these two tries to talk about the ratio.




So, preheating temperature is very important. That means to say, directly from zero to go to a higher temperature while welding happens, it is a sudden change in the gradient. Which can lead to expansion or contraction of the metal, which can lead to cracks.

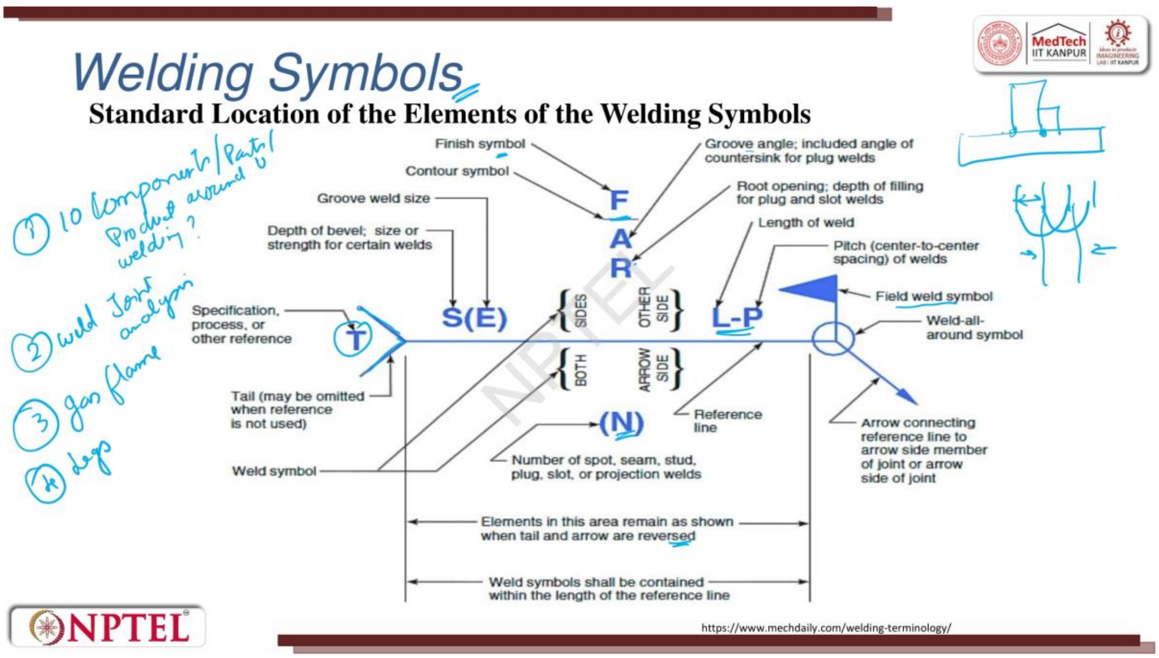
So preheating is required. So basically what we do is we try to take it to 0.3 times, 0.4 times or even 0.5 times. So wherein which we try to release the residual stresses, expand the grains little bit before the welding could happen. So preheating temperature is very important. So what we do is generally we first use the oxyacetylene flame and heat it one go.

which is generally done in pressure vessels. Preheating temperature is the temperature of the base metal surrounding the welding point joints before weld begins. Or before subsequent pass in the multi-pass welding also, we can increase the temperature. It is the minimum temperature required to start welding is preheating temperature. So, you can also start reheating and then do welding or between one pass the other pass also you can do.

Why? Because when we do one pass and the other pass there will not be a drastic solidification and a liquid present. So, this will try to again create a crack. So inter-pass temperature is also tried. In the multi-pass welding, the temperature of the weld area between the weld passes.

The maximum temperature allows to deposit the next pass in the multiple pass. So generally what we are trying to say is if you have two metals which has to be joined. The filling of materials will happen, it will happen layer by layer by layer. So between two layers, you try to have a interpass temperature. The welding operator, one who operates the adaptive control automatic mechanized welding machine is called as a weld operator.

Welding procedure specification is also used. A document providing the required welding variables for a specified application. To assure repeatability and the reliability of the process is called as welding procedure specification. These are all done before the process starts.




So when we look at a typical welding symbol which is represented in a mechanical engineering drawing. You will see that you will have between the joints, they will have these symbols. So here what they will do is the F which is there here starts the finish symbol and you will have a groove angle. If at all there is any angle, there is a groove. Say for example, when we have a T plate, what is the groove angle. So this is the groove angle, right.

So, between two plates there will be a groove or some that is angle. The groove angle included angle of the counter sink for plug welding is given here. Then the root opening, what is the root? This portion, this portion, small root opening is given here. Length of the weld is said, this is L, it talks about the length, how much distance we try to go for welding.

Then pitch between one weld, the other weld. This is one weld, this is the other weld. So what is the pitch? This is the pitch. Between two overlaps what we have.

So length and pitch is talked about here. This is the reference line where they give everything here. Now here in the arrow side, they try to talk about field weld symbol, then weld all around the symbol. So this is all around you have to do welding is given here. The arrow connecting the reference line to the arrow side remember to off joining or arrow side off joint can be done here.

So, this is only for arc welding when we are trying to do see arc is continuous. But when you want to do spot then you are supposed to say how many spots. So, number of spots which are done this is resistance welding we talk about. So element in the area remains as shown when tall and arrow are reversed. This tries to talk about the specification process what is to be done.

T talks about the tail end. Then groove weld size is given, depth of welding is also given. If you look at the specification, all the things which is required for joining is given. What is the depth, what is the pitch, what is the root, everything is given here. So by looking at this symbol, you will try to figure out what welding process to use.

What should be the other preparatory to be done for welding. By understanding all the symbols, we can try to establish what is to be done. Before I close the lecture, I have a few things for you to understand and enjoy the welding chapter. First, you try to make a list of 10 components or parts or products, whatever it is, which is around you Where welding is done.

Where welding is done. Make a list. Then try to understand or observe closely what the heat effect is. Do not use a microscope or anything. You can see when the joining happens and how the joining appears.

So we can try to write it down as weld joint analysis you attempt to do. The third one is you can try to take a spoon or whatever it is. A spoon or a steel pot and put it in the gas flame to see what happens to the temperature. With respect to time, you can see how from a cold one it becomes red hot, right. So you can see the flame one.

And the next one is going to be if you try to see a chip, an icy chip, see how the legs are getting attached to the component. So if you look into all those things, you will see what the beauty of welding is.

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For preparing this lecture, we used the following references. I am just covering the theory. The problem-solving will be done by Dr. Amandeep.

Thank you very much.