Manufacturing Processes – Casting and Joining
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Lecture – 15
Characteristic Features of Welding Processes

Hello and welcome to the course on Manufacturing Processes. We are discussing welding right now and we have discussed already the casting processes earlier. In the welding, I started with the mechanism of welding, what is the physics behind the welding, and you have seen that if the two atoms come very close to each other, then their repulsive and the attractive forces become equal, and they become stable.

That is the mechanism of welding that the two atoms, two different atoms of two different metals or two pieces, they come very close to each other so that they actually get joined together; they are welded. We have seen how the attractive force and the repulsive force act and we said that as they are coming closer to each other, the repulsive force become faster, I mean the rate will be more.

At a point they will be same and then they are getting welded; they are getting stable, they are getting in the equilibrium position. Atoms will be in the equilibrium position. After that, we have seen different kind of welding processes. We said that there are solid state welding, liquid state welding, solid-liquid state welding. Apart from welding processes, we have the mechanical fashioning or the adhesive bonding, those are also the joining processes.

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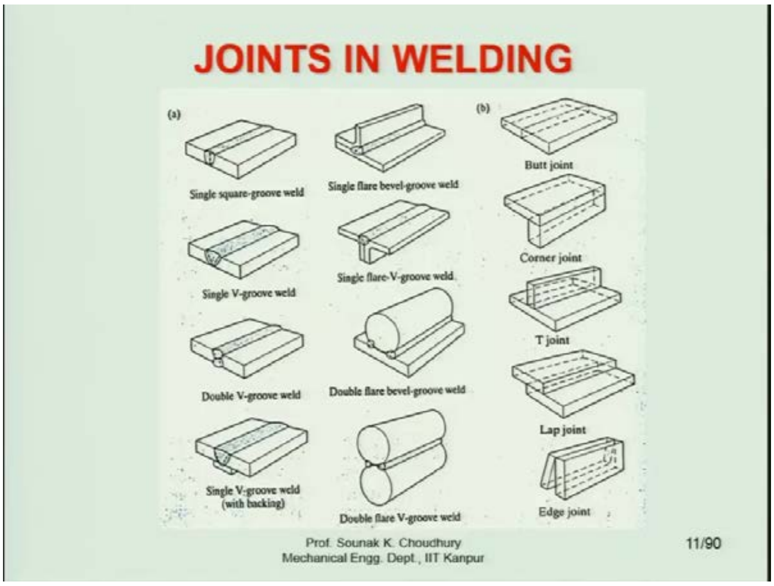

But we will concentrate more on the welding and then, we will discuss also the brazing and soldering process. Next, we have seen the advantages and disadvantages. There are lot of advantages, disadvantages also there are few and mostly, it is very expensive because we have to pay for the labor. We will discuss in more details about the welding processes as we go on.

Next, we started discussing about different kind of joints that are required; that are made during the welding process. If you see the slide, there are these joints that we have already discussed. Single-square-groove weld, single flare bevel-groove weld, single V-groove weld or flare V-groove weld, then this is the Butt joint and this is the Corner joint. Apart from that, we have the double V-groove weld.

Depending upon the type of the parts, we can make either single V-groove or it has to be double V-groove weld, depending on the strength which is required of the weld or depending on the type of the parts. If the parts are like that, so we have a double flare bevel-groove weld like this.

This is the T joint, similar to that; but this is corner joint, and this is the T joint. This is very popular. Like butt joint, we have the lap joint also; where, parts are kept on top of each other. This is the edge joint, where the two parts meet at the edge.

They are at an angle. If these are the parts, similar to that, but here it is the flat, here both of them are barrel type or the drum type, this joint is called a double flare V-groove weld. This is bevel-groove, this is the V-groove. This is the single V-groove weld with backing; instead of double V-groove weld, there is a backing here as you can see .

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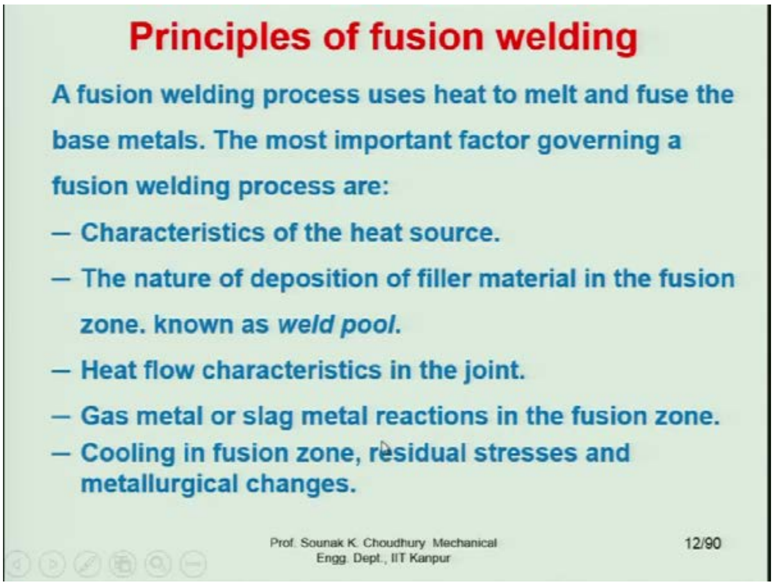

Now, let us see the principles of fusion welding. A fusion welding process uses heat to melt and fuse the base metal. The name itself says that this is the fusion welding. The base metal has to be fused, has to be melted. These are the five very important factors for the fusion welding.

Characteristics of the heat source; what kind of heat source we are using? What are the characteristics? The nature of deposition of filler material in the fusion zone, this is known as the weld pool. How the weld pool will be made; what is the nature of the weld pool? Heat flow characteristics in the joint. How the heat is flowing?

Gas metal or slag metal reactions in the fusion zone. Cooling in fusion zone, residual stresses and the metallurgical changes that is happening. These are the five important characteristics of the fusion weld that we have to take care, I mean take care and keep in mind while performing those welding processes.

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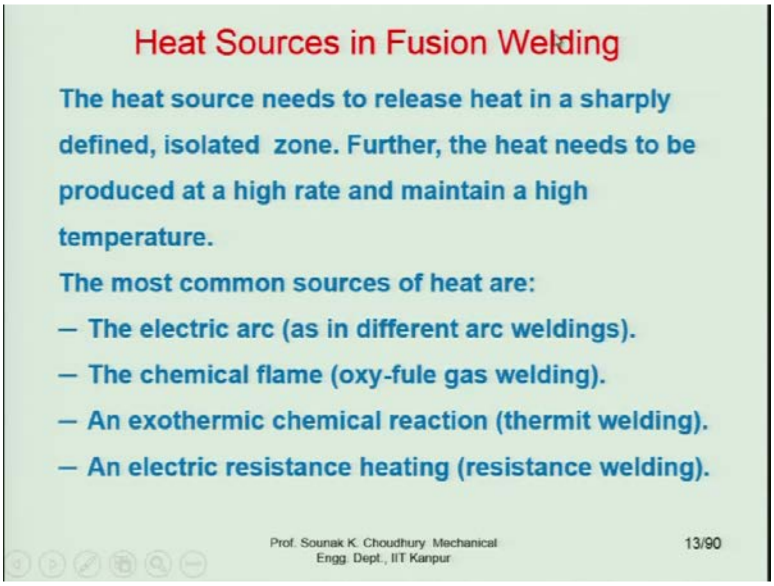

Heat source; the heat source needs to release heat in a sharply defined isolated zone. Further, the heat needs to be produced at a high rate and maintain a high temperature. This is the characteristic of the heat source. It has to be sharply defined, isolated zone and it has to be produced at a high rate and this also should maintain a high temperature. It should not lose its temperature.

The most common source of heat is electric arc as in different arc welding processes. We will discuss that in more details as we go through, how the arc is produced, whether that heat is stable and whether it is decreasing or not, whether it remains as a constant temperature.

The chemical flame like oxy-fuel, oxy-fuel gas welding or it is also called the oxy acetylene and exothermic chemical reaction, we will discuss the thermit welding, there it is the exothermic chemical reaction which evolves heat. Because there is a chemical reaction happening and because of that the heat is produced, that heat is used to fuse the base metal. An electric resistance heating; it is known as resistance welding and is very popularly used.

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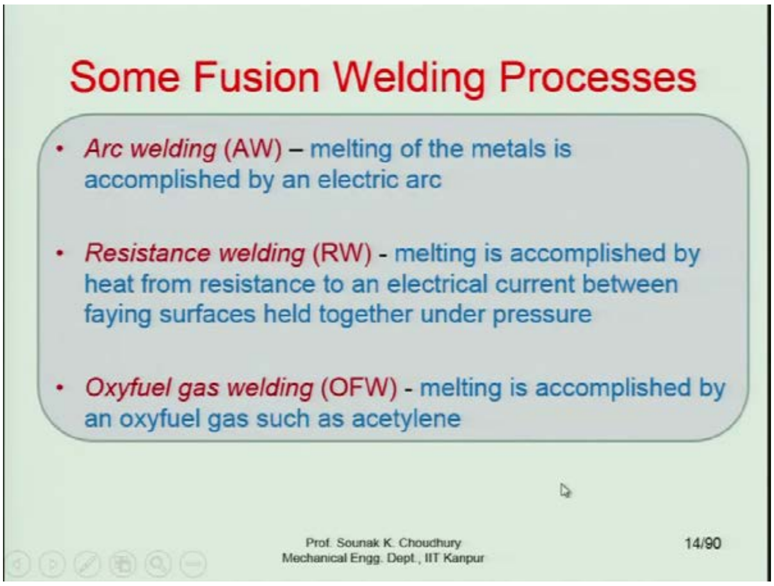

Some fusion welding processes are the following. Arc welding; arc welding is probably one of the most commonly used welding processes. Melting of the metal is accomplished by an electric arc. An electric arc is produced by the anode and the cathode positive and the negatively charged electrodes. Resistance welding is another process where melting is accomplished by heat from the resistance to an electric current between the faying surfaces, held together under the pressure that we will discuss.

Now, the oxyfuel gas welding, this is in here melting is accomplished by an oxy-fuel gas such as acetylene. It is also called the acetylene oxyacetylene welding process. Some solid-state welding processes - these are the diffusion welding. Mind it that all these are the fusion welding, arc welding, i.e. resistance welding and oxy fuel gas welding; where, the heat is used to melt the base metal.

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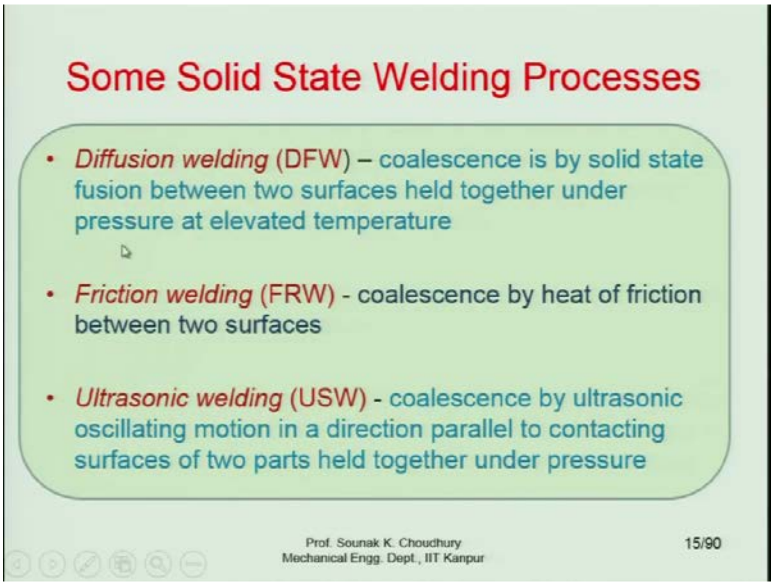

And these are the processes like diffusion welding, friction welding and the ultrasonic welding, where we weld the parts in the solid state. Here, the base metal is not melted. The diffusion welding coalescence is by solid state fusion between the two surfaces held together, under pressure at an elevated temperatures. Temperature is higher and at certain pressure which is exerted to the two parts that are joined together.

Friction welding: coalescence by heat of friction between the two surfaces. We will discuss them that two surfaces like, for example, two cylindrical surfaces are rotated and they are in contact with each other. At high rotation, when they are in contact with each other because of the friction, there will be high temperature produced and then, they can be joined together.

Base metal is not really melted, but at an elevated temperature; at a temperature higher than the environmental temperature. In ultrasonic welding, coalescence is by ultrasonic oscillating motion in a direction parallel to the contacting surfaces of two parts held together under pressure. Ultrasonic welding is very popularly used because of the high ultrasonic frequency, it is about 10 to 15 kilo Hertz, it can go up to 25 kilo Hertz.

This is the vibration that occurs and because of that vibration, the heat is produced; elevated temperature is produced, and the two parts can get welded. We will discuss it later.

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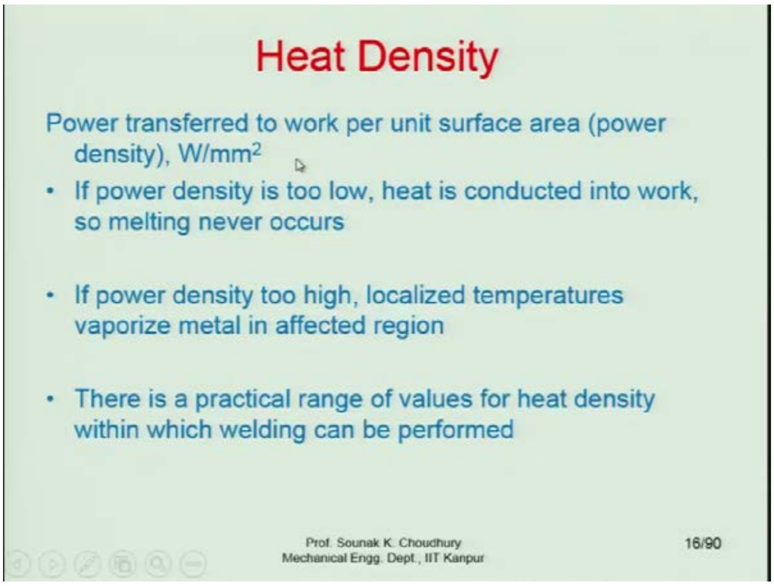

Heat density; power transferred to work per unit surface area. This is $\left[\frac{Watt}{mm^2}\right]$. I already told you that in some of the welding processes, I showed it to you in a tabulated form how different kind of welding processes, how much power they need or the power density they need. This is in $\left[\frac{Watt}{mm^2}\right]$. If power density is too low, heat is conducted into work.

Melting never occurs, this I already told you. If power density is too high, localized temperatures vaporize metal, this affects also the region. And there is a practical range within which the welding can be performed.

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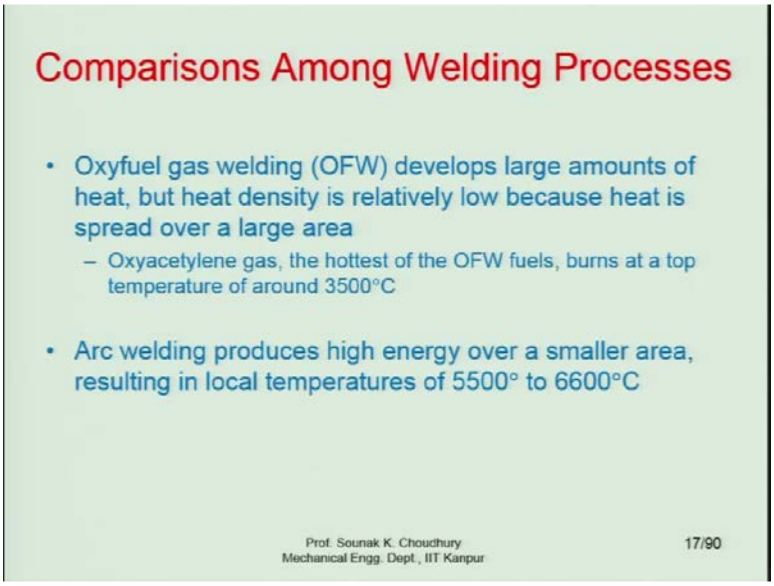

Comparison among the welding processes: the oxyfuel gas welding develops large amount of heat, but the heat density is relatively low in the case of the oxy fuel gas welding. Because the heat is spread over a large area. Now, as an example, I told you about those ion beams or the beam technology. In beam technology, it is concentrating at a very tiny spot and by tiny, very tiny I mean to say that it can be in micron level.

There we have seen that the power concentration is about 1000 and more than 1000 $\left[\frac{Watt}{mm^2}\right]$. it is very high; but here in the oxy fuel, it is relatively low because it is spreaded over a large area. Now, oxy acetylene gas; the hottest of the oxy welding fuel burns at a top temperature of around 3500^0C. When you adjust those flames, those are the blue flames, yellow flames, red flame and so on.

The maximum temperature that you can get is about 3500^0C by adjusting the burner. The arc welding produces high energy over a smaller area, resulting in local temperature of much more than oxy acetylene gas. It is about 5500 to 6600^0C. This is the arc welding. Because this is over a smaller area and oxyacetylene gas is spreaded over the larger area - that is the difference.

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Features of a fusion welding welded joint: These are the following four features. Typical fusion weld joint in which filler metal has been added consists of the fusion zone one, weld interface, heat affected zone and the unaffected base metal zone. These are the basic four features in the fusion welding process.

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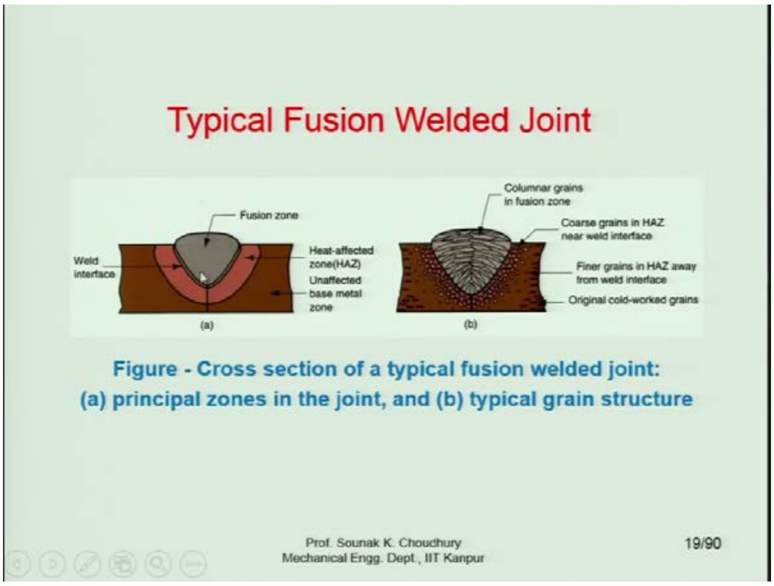

Here we can see the fusion zone, where the fusion process taking place. This is the fusion zone. Weld interface is here; weld interface is between the fusion zone and the heat affected zone. Heat affected zone is the zone, where the structure of the material has changed because of the heat that has been produced in the fusion zone, which has certain area.

That is called the heat affected zone and beyond that heat affected zone, this zone remains unaffected by the heat and therefore, it is called the unaffected base metal zone. And then, in these three zones, what happens to the grains are the following. Like here we have the fusion zone. Since the cooling is taking place at a slower rate, therefore, these grains are the columnar grains.

This is in the fusion zone. Here in the heat affected zone, the grains become coarser near the weld interface and in the unaffected zone, the original cold work grains, we get; that is the finer grains. But in the heat affected zone, which is away from the weld interface, there the grains are finer.

Now, there are two different kind of grains; one area where we have the coarse grain and this is the heat affected zone which is closer to the fusion zone and because of that, the rate of solidification will be slower. Therefore, the grains are bigger.

But in this, this is closer to the original cold work grains and therefore, it will cool down at a faster rate and the grains will be finer. That means, in the heat affected zone, you will have the finer as well as the coarse grains; structure will be different.

What happens in the case of the fusion welding process in the fusion weld zone? Here, it is the principal zone in the joint and the typical grain structure. You can see the typical grain structure that actually may occur.

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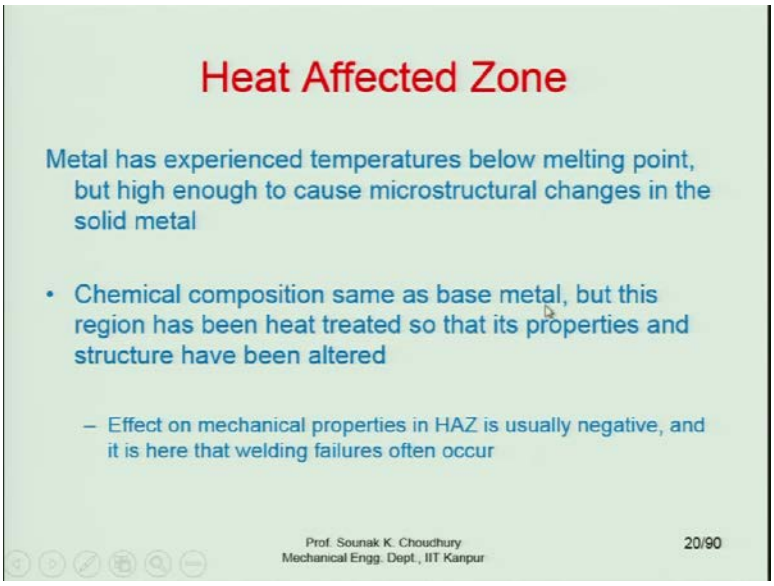

Heat affected zone: metal has experienced temperatures below melting point. It is not yet melted, but high enough to cause micro structural changes in the solid metal. Keep in mind that the heat affected zone is highly heated up because of the fusion taking place in the adjoining areas.

Like in here. But still this heat affected zone is not melted, it's temperature is very high; but it is not melted yet, but there is a change in the structure, as you can see the grain structure is different; the micro structural changes have occured in the solid metal.

Chemical composition is the same as in the base metal in the heat affected zone, but this region has been heat treated so that its properties and structure have been altered. It is heat treated, that is why the grain structure is different. Grain structure is a combination of the coarse and the finer grains. Coarse grains because the cooling down is slower, and the cooling down is faster because it is close to the original cold work grains.

Therefore, the grains are finer. In the heat affected zone, the structure is very different as you can see. It can be coarse grains, it can be finer grains and so on. Effect on mechanical properties in the heat affected zone is usually negative and it is here that welding failures often occur. This is a zone which is sort of a dangerous zone because the failure may occur not where the welding process has gone into, but in the adjoining area, that is the heat affected zone.

That is why it is said that the effect on mechanical properties in the heat affected zone is usually negative because as you have seen the structure is different. Here we have the coarse grains. Here the strength is less, strength will be more where we have the finer grains.

Therefore, it has two different kind of strengths in the heat affected zone and the weld can fill in along this. Now, effects of the solidification of weld related to cooling, these are the three effects that we normally observe. Two of them we have seen in case of casting.

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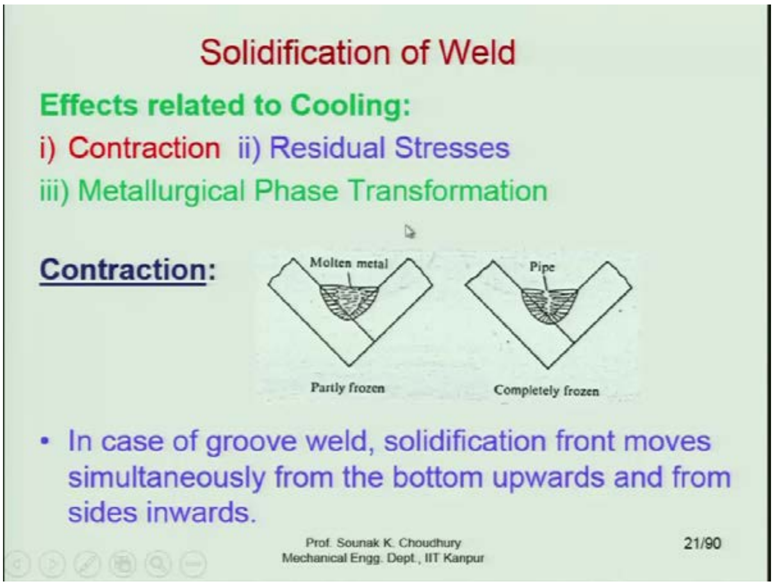

When cooling down, like in casting, in welding also in the welded zone, it can have the contraction or the shrinkage, that we have seen in casting. Therefore, it may have residual stresses and the residual stresses can adversely affect.

In many of the metals, residual stresses after the heat treatment have to be removed by another heat treatment process and because of the residual stresses many of the parts may fail, if we do not remove the residual stresses. I will give you an example. Let us say you take a glass that you use for drinking water.

Let us say this is a very cheap glass, and you can also get a very expensive glass. Drop on the cement floor, you will see that the glass which is inexpensive will shatter in small pieces. And this another one may crack, may shatter, but not in pieces like the front glass or shield glass of the automobile.

Because those expensive glasses are heat treated and they do not have any residual stresses and the cheaper glass because it is cheap, so they did not go through the heat treatment and there are residual stresses. So, when it drops, it will be shattered in small pieces because of the residual stresses.

Similarly, many engineering parts may fail because of the residual stresses and residual stresses may happen because of the temperature gradient and so on.

And finally, we have the metallurgical phase transformation. The contraction is where the welding process has gone in. These are the two parts which have been welded and this is the molten metal.

Like in case of casting, the columnar grains will go towards the center while solidifying and this will start solidifying. Finally, what will happen is that there will be a pipe kind of a contraction or the shrinkage cavity similar to one that happens in the casting. After it is completely frozen, when the molten metal in the welding zone has been solidified.

It will form a pipe like shrinkage cavity which is due to the contraction. In case of groove weld, solidification front moves simultaneously from the bottom upwards and from side inwards. Let us say this is the groove type.

From sides, it will go to the center here; from here, it will go from up to the top, from bottom to the top like that and they will come here and meet at the middle like we have seen like in case of casting.

In this figure, it is partly frozen when the columnar grains have started moving and here still we have the molten metal. When it is completely solidified, this columnar grain of the dendrite type that we have we have told in the case of casting, is complete and there is a kind of a pipe formed; this is the contraction.

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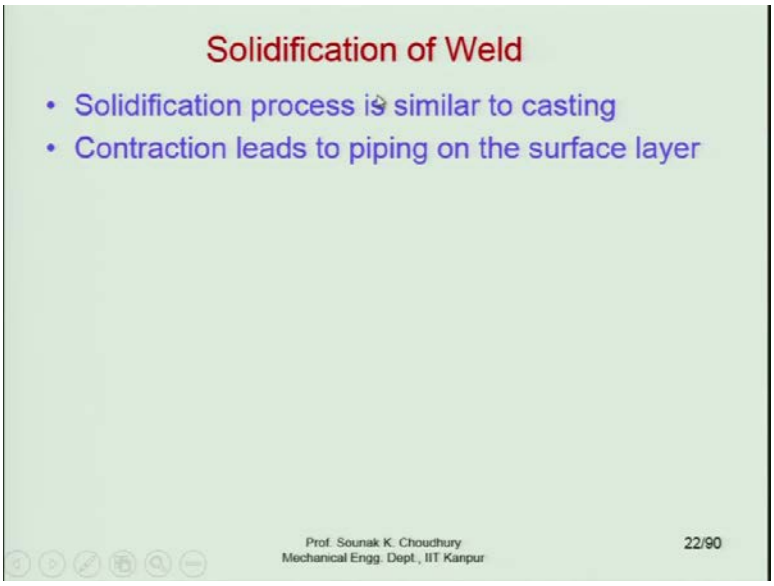

Solidification of weld: the solidification process is similar to casting as I said. Contraction leads to piping on the surface layer.

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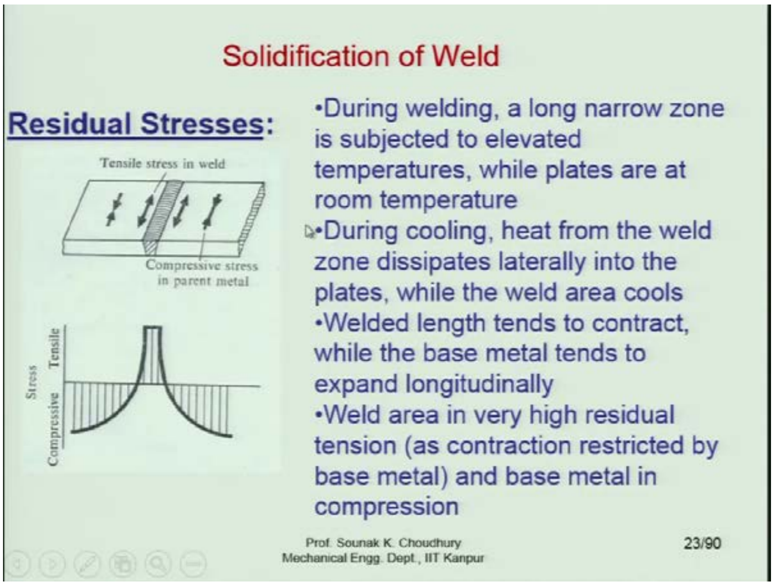

Let us talk about the second aspect which is the residual stress. Here, these are the two parts which are welded, this is the weld pool. Here what happens is that adjoining to the weld, because of the heat, there is a tensile stress in the weld. Because it is highly temperature affected, but this is comparatively less affected by the temperature since there is a colder region. Here, we will have the compressive stress in the parent metal.

During the welding therefore, the stress will be compressive and here it will be tensile. So, this is the curve that we can get because of the tensile and because of the compressive stresses, jointly applied to the welded parts. Now, during welding, a long narrow zone is subjected to elevated temperature. Here, in this zone the elevated temperature has been applied, while plates are at room temperature.

During cooling, heat from the weld zone dissipates laterally into the plates, while the weld area cools. When this area is cooling down, the heat is dissipated laterally, welded length tends to contract, while the base metal tends to expand longitudinally because of the heat spreaded to this metal. So, it try to get expanded and this will be contracted because it is cooling down.

Weld area is in very high residual tension because of that, as contraction restricted by the base metal. It will be contracted because the temperature is reducing when it is cooling down, but this will be restricted by the base metal because the base metal will not be contracted, and it will restrict the contraction of the welded zone, because the base metal is in compression.

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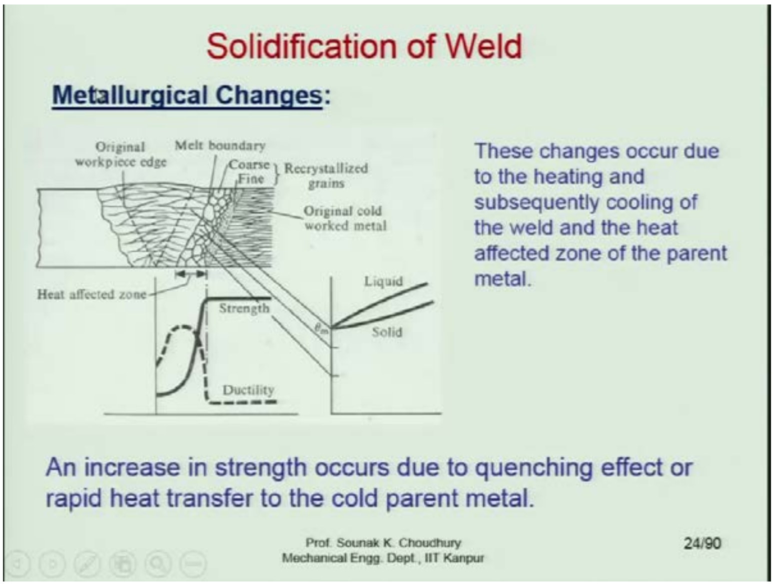

Now, the third feature in the metallurgical changes. Here are the metallurgical changes given in details and here if you see the original work piece edge here given in the dotted line. This is the melt weld pool and the melt boundary is here. This has been melted. Here we have the coarse grain in the heat affected zone. This is the heat affected zone and we have mentioned that in heat affected zone, we will have both cold grains and the finer grains.

Coarse grains are formed in that part, which will be adjoining to the melt boundary and finer grains will be where it will be adjoining to the original cold worked metal; here it is. These grains in the heat affected zone will be recrystallized grains and recrystallization taken place because of the heat that has been dissipated in the heat affected zone; but it has not melted.

This is called the recrystallization and the recrystallize grains will be coarse and the finer grains. These changes occur due to the heating and subsequently, cooling of the weld and the heat affected zone of the parent metal.

This is the strange phenomenon that happens during the welding process and that we are calling these changes as the metallurgical changes because we will see in our next discussion session that the metallurgical properties change. Therefore, these we call as the metallurgical changes.

The rest of the material in the welding we will discuss in our next discussion class.

Thank you for your attention.