Manufacturing Processes – Casting and Joining
Prof. Sounak Kumar Choudhury
Department of Mechanical Engineering
Indian Institute of Technology Kanpur

Lecture – 14
Introduction to Joining Processes

Hello and welcome back to the course on Manufacturing Processes - Casting and Joining. We have discussed so far, the casting processes in details. And from this session I would like to discuss the Joining Processes.

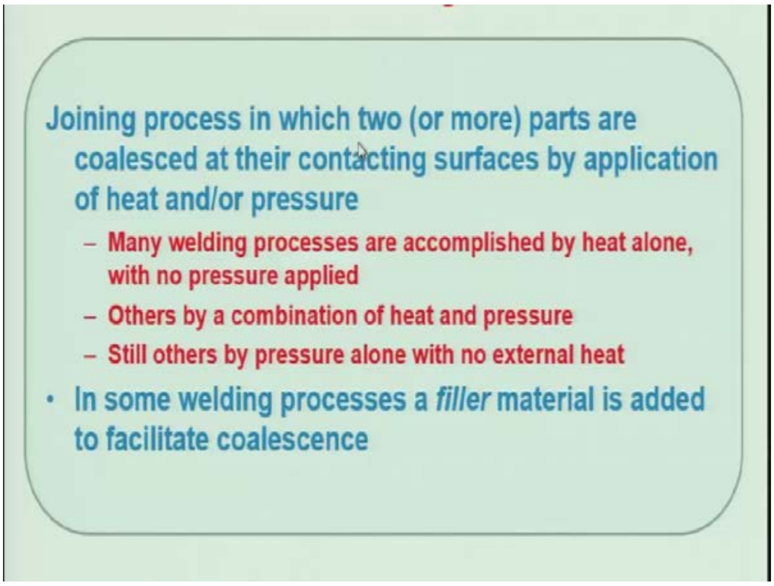
Joining processes basically are mass addition processes. I will remind you that the final product or the end product can be obtained from the raw material by either the mass removal process or the constant mass operation or the mass addition process.

We have discussed the constant mass operation, which is casting where the volume operation does not change; mass does not change from the raw material that you started with. In case of joining, the two materials are joined together; two parts are joined together.

That is done by welding processes, or by rapid prototyping, which is a recent technology where layer by layer you add the material and finally, it takes the shape of the final product.

These are the processes that we will be discussing, but we will emphasize of course, more on the welding and apart from the welding, in the joining processes we will also discuss the brazing and soldering. Those are not really welding process.

(Refer Slide Time: 02:06)



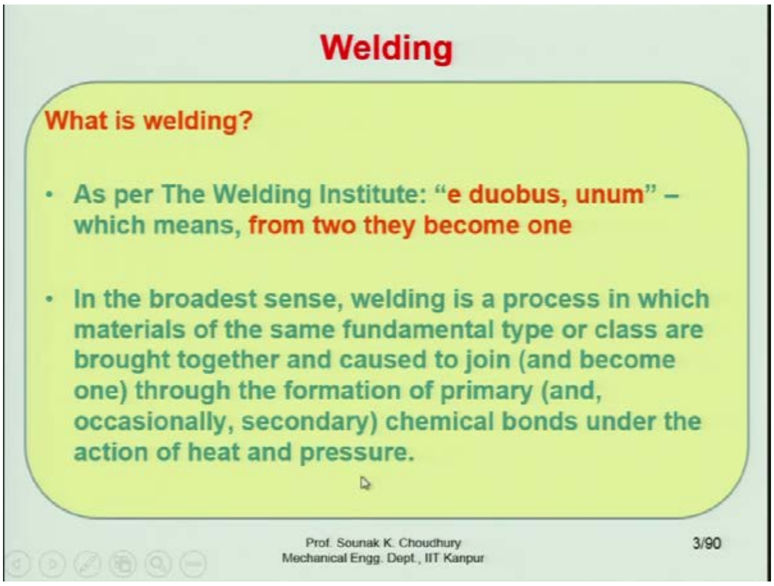
But we will be discussing because they also come under the joining processes. Joining process in which two or more parts are coalesced at their contacting surfaces by application of heat and/or pressure - that is the welding.

So, welding can be defined as the joining process in which the two or more parts are joined together coalesced at their contacting surfaces and that can be by application of heat pressure or both simultaneously. Many welding processes are accomplished by heat alone.

There are welding processes that can be performed only by heating without applying any pressure. Some welding processes are performed only by applying pressure and some are there which are combination of the heat and the pressure.

Still, others by pressure alone with no external heat that I already told you. In some welding processes, a filler material is added to facilitate the coalescence. Many of you must be aware of that there is an additional filler material that is added to the welding zone so that the parts are coalesced, parts are joined together.

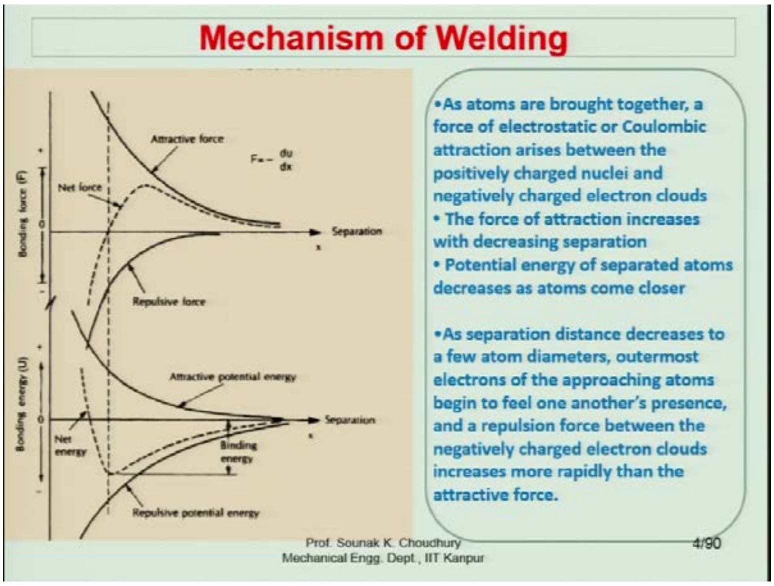
(Refer Slide Time: 03:33)



Let us see what is the welding. As per the Welding Institute, the definition is "e duobus, unum" that is somehow said; that means that from two they become one. There are two parts they have been joined and they became one. That is actually the I think it is in Latin "e duobus unum" and that does mean that from two they become one. This is what the welding is defined of course, that is in one word.

In the broader sense, welding is a process in which materials of the same fundamental type or class are brought together and caused to join and become one through the formation of primary and occasionally the secondary chemical bonds under the action of heat and the pressure. So, heat and the pressure or the pressure without heat that is also possible.

(Refer Slide Time: 04:44)



Let us see what is the mechanism of welding. What happens when the two materials are coming closer to each other, why they are getting joined, what happens?. If we see this curve here - there is a bonding force along the Y axis and along the X axis the distance between them that is the separation.

As atoms are brought together, a force of electrostatic or coulombic attraction arises between the positively charged nuclei and the negatively charged electron clouds. What does it mean? One atom will have outer electrons in the orbit and in the middle, there is neutron which is plus, and electron is negative or minus.

When they are coming closer, these electrons and the neutrons will have an attractive force. So, they attract. In fact, what happens is; when they are coming very close to each other, then their outer electrons will be shared by both the nuclei of the two atoms. Let us say two atoms are coming closer to each other.

Outer electrons of both the atoms will be shared by both the nuclei. Although, when atom is separate, outer electrons will be attracted by its own nuclei. What is said is that atoms are brought together, a force of electrostatic or coulombic attraction arises between the positively charged nuclei which is in the in the middle say at the centre and negatively charged electron clouds at the periphery.

What is electron clouds? Meaning that is not one electron, that is several electrons are there in orbit. The force of attraction increases with decreasing separation; meaning as they are coming closer as the separation decreases or the distance is decreasing, then these attractive forces will be more. Potential energy of separated atoms decreases as atoms come closer.

As separation distance decreases to a few atom diameters, outermost electrons of the approaching atoms begin to feel one another's presence and a repulsion force between the negatively charged electron clouds increases more rapidly than the attractive force.

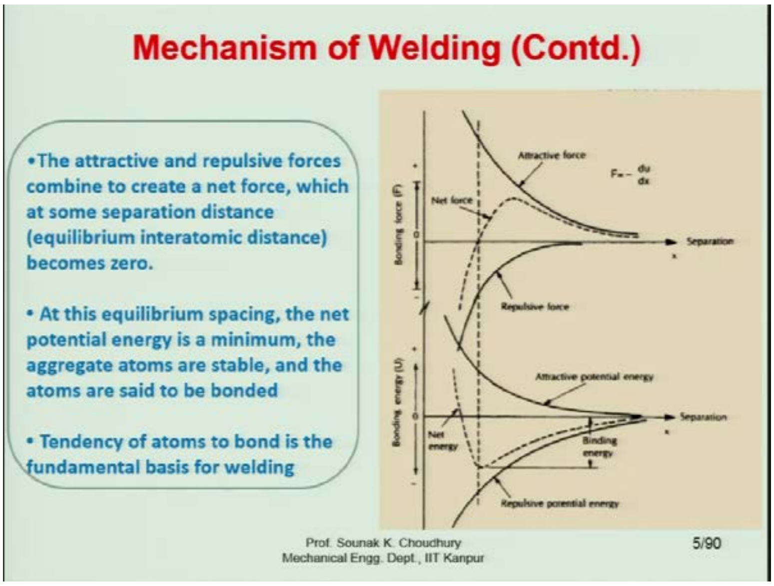
What happens here is, these are the negatively charged electrons. Electrons between them and the nuclei between them, because nuclei are positively charged, two atoms will also have a repulsive force, because nuclei can attract the electrons.

Positive nuclei can attract negatively charged electrons, but when they are coming very close to each other, attractive force is increasing, because of the electron clouds and the nuclei; however, there will be a repulsive force also because the negatively charged electrons of both the atoms will repulse each other and the positively charged nuclei of both the atoms will be repulsing each other.

What happens is that repulsive force becomes more than the attractive force. That is why it increases more rapidly, the increase of this will be more than the attractive force. This is what actually is shown here; that this is the attractive force, this is the repulsive force and as you can see the repulsive force is becoming more than that and the net force.

The bonding energy will be like this. Attractive potential energy and the repulsive potential energy and the net energy can be given as shown by the dotted line. This is with respect to the distance between the two atoms, that is a separation, that is, as the distance is increasing. As they are getting separated out or as the distance is became becoming less as their coming closer to each other.

(Refer Slide Time: 09:54)



The attractive and repulsive forces combine to create a net force, as I said which at some separation distance always becomes zero. Let us say, this is the separation distance. If you take the net force it will cross this line. So, at this point, this net force is equal to zero. At this equilibrium spacing. Once this is zero means the repulsive force and the attractive force become same.

This is an equilibrium position. At this equilibrium spacing, the net potential energy is minimum. Net potential energy you can find out from here; this is the net energy, this is minimum. The aggregate atoms are stable, because repulsive force and the attractive forces are the same and the atoms are said to be bonded; meaning they are actually stable, you cannot separate them out now.

So, now they are bonded; that is welding. Then two atoms of two different materials, if you can put them very close to each other, so that their electrons can be shared by both the nuclei, that is the welding process. How you are making that possible, that is, through either temperature or through pressure or through both of them that is what we are defining by the welding.

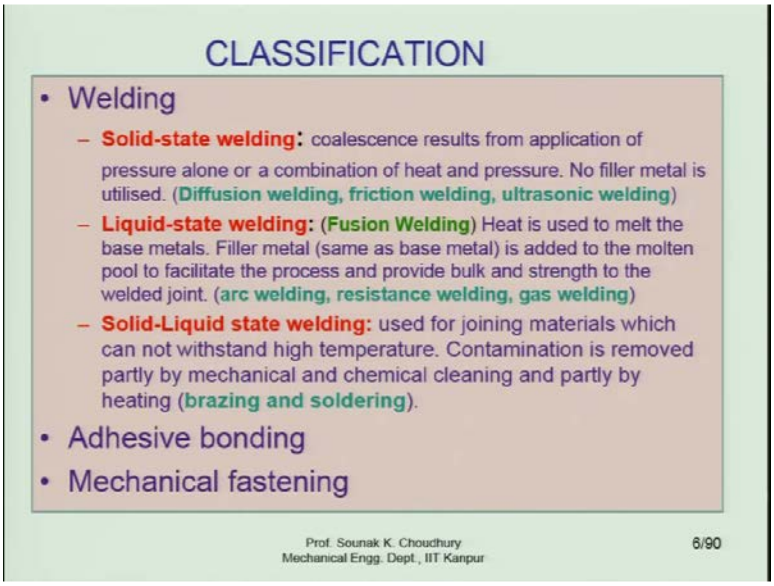
Tendency of atoms to bond is the fundamental basis for welding. That is a basic principle of welding that they are very close to each other; so close that atoms are in equilibrium position; repulsive force and the attractive force are same.

If you remember those slip gauges that you use probably in the metrology lab for measuring the gap, the distance - those slabs. They are very smooth. In fact, when you are using them for measurement, you actually rub them with the alcohol or with spirit so that there is no dirt or grease on the top so that the measurement can be accurate, because you have to measure within the error of micron sometimes with the slip gauges or fraction of millimeter.

If you put those two slip gauges together, it is very difficult to separate them out. That is a kind of a welding that has taken place because this these two surfaces are so clean And so nascent that there atoms are almost in the equilibrium position.

They really do not get welded, because we can separate out with certain force applied, but they stick to each other very rigidly, because they have come very close to each other. So, the atoms are getting shared by both the nuclei of these two atoms, and it is difficult to separate out. Same thing happens in case of the welding.

(Refer Slide Time: 13:44)



This is the mechanism of welding. How the welding takes place?. What is the physics behind the welding?. Classification; there are different kind of welding processes. Basically, we will be looking at three different kind of welding processes.

Solid-state welding; in solid state welding, the coalescence results from application of pressure alone or a combination of heat and pressure. That is why it is called solid state; Basically, we will be talking about the welding of metals. Two pieces of metals in solid-state welding are not melted. They are in the solid form and they can be welded.

No filler metal is utilized in this case. Diffusion welding, friction welding, ultrasonic welding - these are the examples of the solid-state welding. We will discuss them separately in details. Liquid-state welding, which is also called the fusion welding, because the materials of both the parts are fused. Suppose these two parts are to be welded, both of them will be fused, that is why it is called the fusion welding or liquid state welding.

Heat is used to melt the base metal. Sometimes filler metal, which is the same as the base metal, is added to the molten pool to facilitate the process and provide bulk and strength to the welded joint. The filler metal is added so that the strength or the bulk could be more.

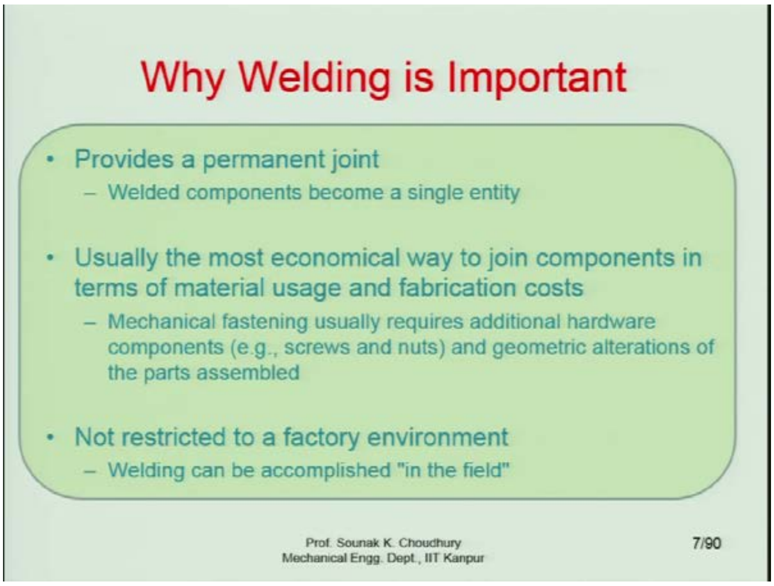
Therefore, the bulk, and therefore the strength should be more of the joint. Examples are arc welding; we will discuss in details resistance welding, gas welding. The third category is the solid liquid-state welding. Here it is semi solid, semi liquid used for joining materials which cannot withstand high temperature. They will be thermally deformed or burnt. For those materials you do not apply much heat.

Contamination is removed partly by mechanical and chemical cleaning and partly by heating. Examples are brazing and soldering. This is not really a welding process, but this, as I said, comes under the joining, but this is called the solid-liquid state welding somehow. In the joining, apart from welding there is adhesive bonding that you all are familiar with.

Even the metal parts are being joined by glues; there are special industrial glues, adhesive that is used for joining the two parts, even the metal. Plastic parts of course can be joined, it is being used for a very long time, but even the metal parts can be joined using the special purpose glues.

Mechanical fastening - nut bolts, different kind of screws and so on. These are the three basic types of the joining processes - welding, adhesive bonding, mechanical fastening. Of course, we said that brazing and soldering somehow, not everywhere you will see that brazing and soldering come under the welding category.

(Refer Slide Time: 17:44)



Why welding is important? Welding provides a permanent joint that is one. Welded components become a single entity. Usually, the most economical way to join components in terms of material usage and the fabrication costs. Mechanical fastening usually requires additional hardware components, for example, screws, nuts and geometric alteration of the parts assembled.

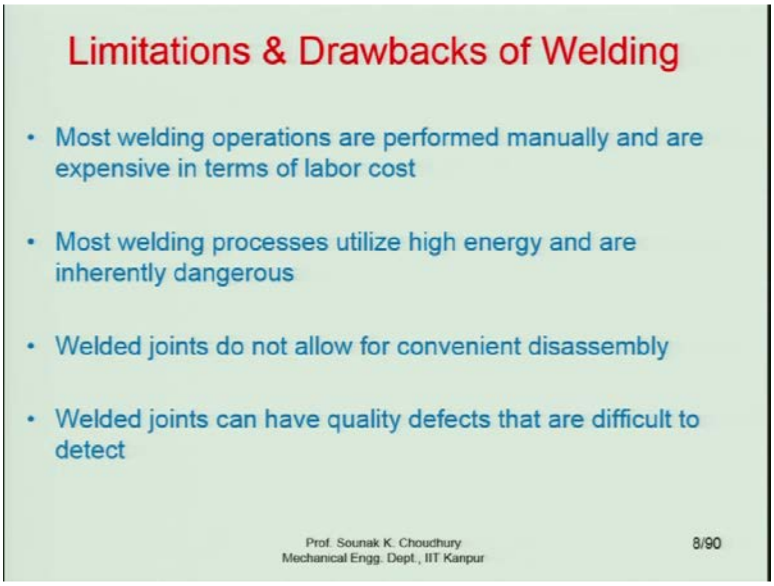
That is why we say that this is most economical way to join the components. Not restricted to a factory environment. I mean welding can be accomplished in the open field.

There are portable welding machines, those portable welding machines can be taken to some remote areas and the welding can be performed. By the way, you must have heard about the undersea welding; that means, under water welding. So, there are ways to weld under the water.

And the t pipe line for taking the raw petrol, raw fuel from one place to another place, we use the pipes of very big diameter and sometimes, from one country to another country through the ocean, through the sea.

Those pipes have to be welded and that sometimes the welding has to be done under the water, because the repairing has to be done also. And those processes also exist. Of course, in this course we will not discuss the underwater welding, but all other different kind of welding processes will be discussed.

(Refer Slide Time: 19:47)



Limitations and drawbacks. We have seen that this is a permanent joint, economical it can be used anywhere, but there are some drawbacks or the limitations. Most welding operations are performed manually, and they are expensive in terms of labor cost.

Particularly it is the experience of the labor for which we are paying high cost of the labor. Not that everybody will be able to do the welding of the same quality, it depends on the experience.

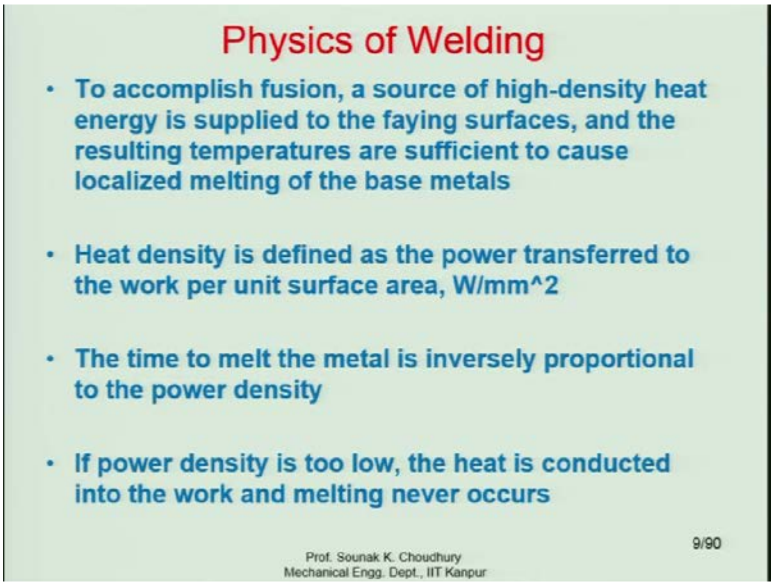
A good, experienced worker can do the welding in a very nice way and this is very important particularly in some cases like, the pipe joining, seam welding and all these cases where you cannot afford to have any leakage of gas. And this is very important. Those highly skilled workers demand very high wages and that is why this process becomes expensive.

Most welding processes utilize high energy and they are inherently dangerous; dangerous, because of the sparks. You must have seen that when welding is performed you cannot see the welding spot, because those rays of light is coming out are the ultraviolet rays and that is very harmful for the eyes. So, you have to take special precautions by wearing special glasses and so on.

Welded joints do not allow for convenient disassembly. Sometimes, they are permanent. So permanent that you cannot cut it, you have to cut the adjoining places not the spot where it is welded. Once it is welded, it is permanent, you cannot really separate it out.

Welded joints can have quality defects that are difficult to detect. There are processes by which these detections are made, but they are very expensive, because it is difficult. Welded joints defects are very difficult to detect. These are the four basic limitations or the drawbacks of the welding process.

(Refer Slide Time: 22:20)

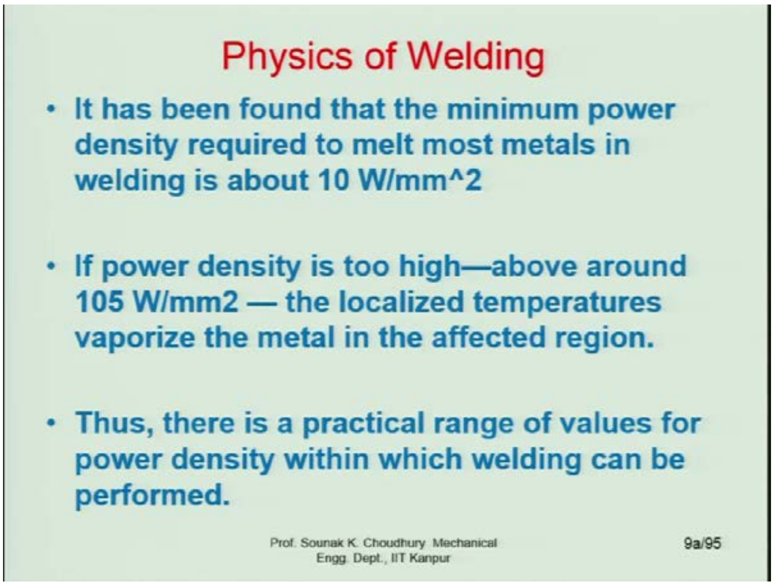


Physics of welding: we have discussed the mechanism, accomplishing fusion; source of high-density heat energy is supplied to the faying surfaces, to those surfaces which are to be joined and the resulting temperatures are sufficient to cause the localized melting of the base metal.

Heat density is defined as the power transferred to the work per unit surface area; that is $\left[\frac{Watt}{mm^2}\right]$; Watt is the power that per unit area you are supplying. The time to melt the metal is inversely proportional to the power density and if the power density is too low, the heat is conducted into the work and the melting never occurs.

You understand the danger; danger is that we have to have a very high power density so that the melting could be taking place only where it is getting joined. If the power density is less, in that case, it will flow to the body of the metal and the localized heating will not be taking place, instead the body of both the surfaces or both the parts will be heated up.

(Refer Slide Time: 23:49)



It has been found that the minimum power density required to melt most metals in welding is about 10 $\left[\frac{Watt}{mm^2}\right]$. As we said that high density is required. And even 10 $\left[\frac{Watt}{mm^2}\right]$ is supposed to be very high density. We will see later on that there are certain processes where very high heat density is used by using the ion beam plasma arc.

All those electron beams, for example. So, those welding processes we will also discuss here, and we will see that by using the ion beams, electron beams or the plasma arc we can actually create a very high density of heat and a very tiny spot can be heated up very effectively. As you can see that most of the metals require about 10 $\left[\frac{Watt}{mm^2}\right]$. This is the power density.

This power density is too high. More than about 105 $\left[\frac{Watt}{mm^2}\right]$, the localized temperatures vaporize the metal in the affected region. It may so happen that due to a faulty regulation or power density becomes all of a sudden very high and if it goes more than 105 $\left[\frac{Watt}{mm^2}\right]$ most of the metals will vaporize. So, that is also a danger.

Low power density once again will not melt, because it will be distributed to the body. High power density will melt so much that it will vaporize the metal. It will not be effective as well.

Normally that depends on the type of the metal that you are using for joining. Different kind of metals need different power density.

(Refer Slide Time: 25:59)

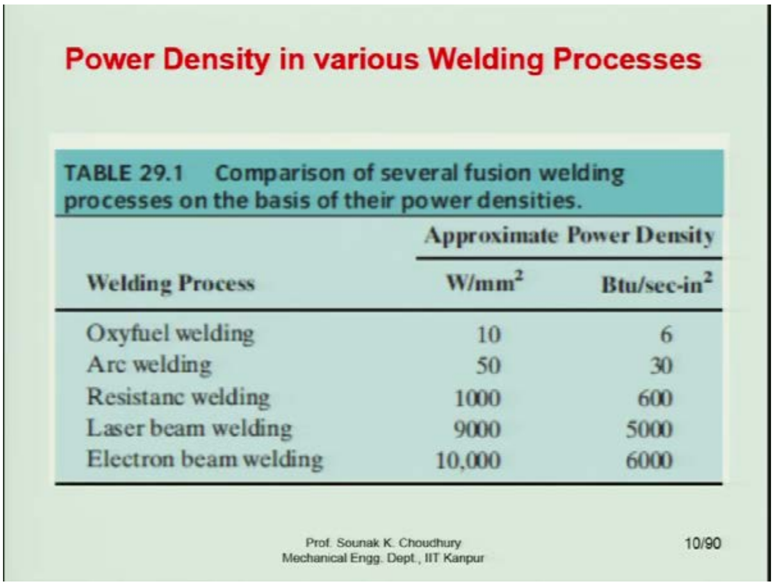


TABLE 29.1 Comparison of several fusion welding processes on the basis of their power densities.

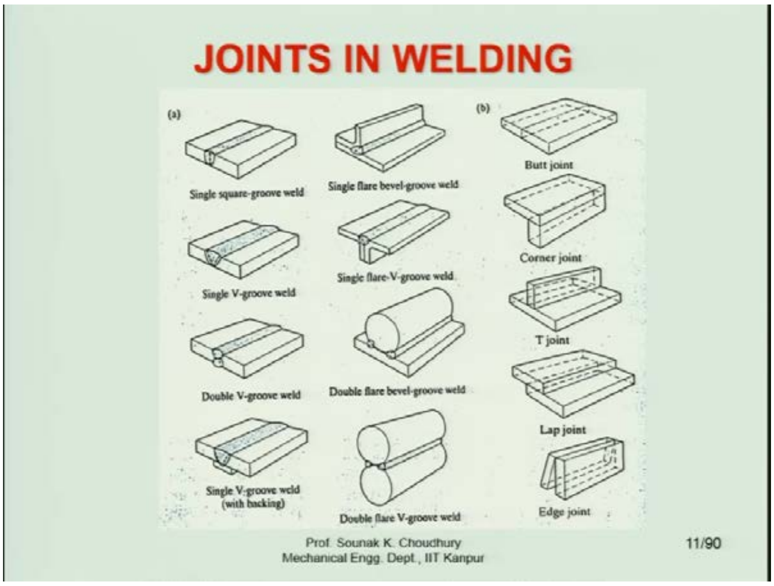
Welding Process	Approximate Power Density W/mm^2	Approximate Power Density Btu/sec-in^2
Oxyfuel welding	10	6
Arc welding	50	30
Resistanc welding	1000	600
Laser beam welding	9000	5000
Electron beam welding	10,000	6000

Let us take some examples. There are different kind of welding processes and we will look into those processes, but before going through these processes, let me tell you which process uses how much power density.

The oxyfuel welding needs about 10 $\left[\frac{Watt}{mm^2}\right]$. Arc welding needs about 50 or uses 50 $\left[\frac{Watt}{mm^2}\right]$. This is for your idea; this is taken from the handbook. Resistance welding for example, uses very high power density; this is 1002 $\left[\frac{Watt}{mm^2}\right]$. Laser beam, electron beam, as I said, are of very high power density processes, because these are the high power density which melt and evaporate a very tiny spot of any material.

W will see that with this kind of high-power density, how the electron beam, ion beam or the laser beam can operate. You can see that depending on the welding process, there are different kind of power density used by different welding processes.

(Refer Slide Time: 27:24)



These are the different kind of joints in welding. We can have single square-groove weld; this is the type of the joint or we can have the single flare bevel-groove welded weld. When the welding is made in this way and these are the parts, then this joint is called the single bevel-groove weld.

This is a butt joint; this is very popularly used. This is the single V-groove weld. Specially, this groove is created for making that weld and these are the two faying parts that are joined together. These are the two L-shape parts, and they are joined like this, as shown in the diagram.

This is the joint which is called the single flare-V-groove weld. This is the square groove weld. This is called the single flare-V-groove weld because it is in the shape of the V. This is in the shape of the V as well these are the corner joints. The two parts are like this and they are put on top of each other like that they are joined.

These are the corner joints. There are various other joints, and we will discuss other aspects of welding in our next lecture session.

Thank you for your attention.