Joining Technologies of Commercial Importance
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Lecture - 04
Heat Generation in Welding

Hello, I welcome you in 4th class of this subject Joining Technologies for the metals. In the last lecture, we have seen the classification of welding as well as we have also seen that how important is to use the heat in the different joining processes and for what the heat is used.

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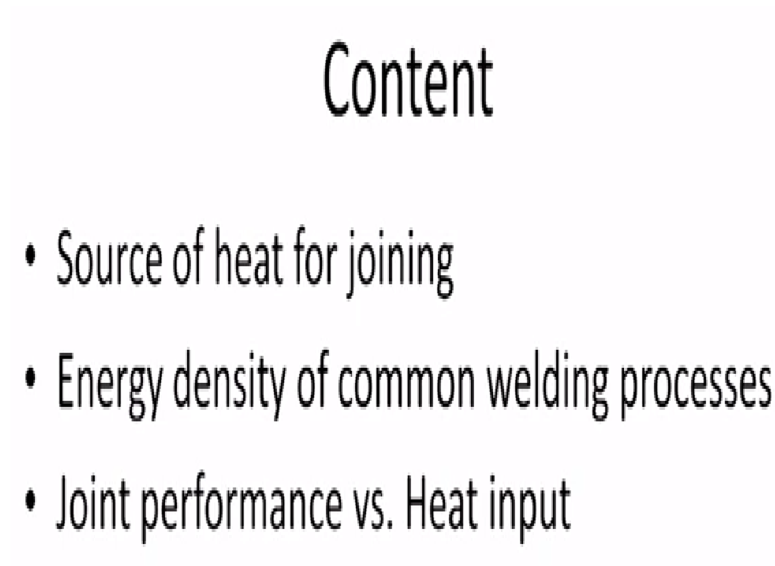

You know that whenever heat is used during the joining processes, you will see that we have to use one or other source of the heat, which will deliver the required heat for either softening purpose for the fusion of the faying surfaces to facilitate the diffusion. So, these are all the three fundamental approaches to lower the yield strength of the metal. So that interfacial deformation or the bulk deformation can be facilitated.

Energy density associated with the heat source is very important because it determines the amount of heat actually required for the given purpose. Like say, for the fusion welding the higher energy density process requires less heat to be delivered for facilitating the fusion of the faying surfaces as compared to the low energy density processes. Energy density associated with a given heat source is very important from the welding and the joint performance point of view.

And so that is why we have to see that how the joint performance is affected with the application of the heat or the amount of heat, which is being delivered. And in the last lecture, we have seen that whenever heat is delivered, heat is delivered for the 3 or 4 main purposes one is for the cleaning purpose, so that by evaporation or by fracturing of the oxides or by decomposition of the oxides this cleaning is a facilitated.

Yield strength is lower so that the surface layer or the bulk deformation is facilitated. The diffusion is accelerated at elevated temperature so that the different bonding can be done at the earliest ineffective way and for the fusion welding processes melting of the faying surfaces is facilitated with the help of the heat being applied.

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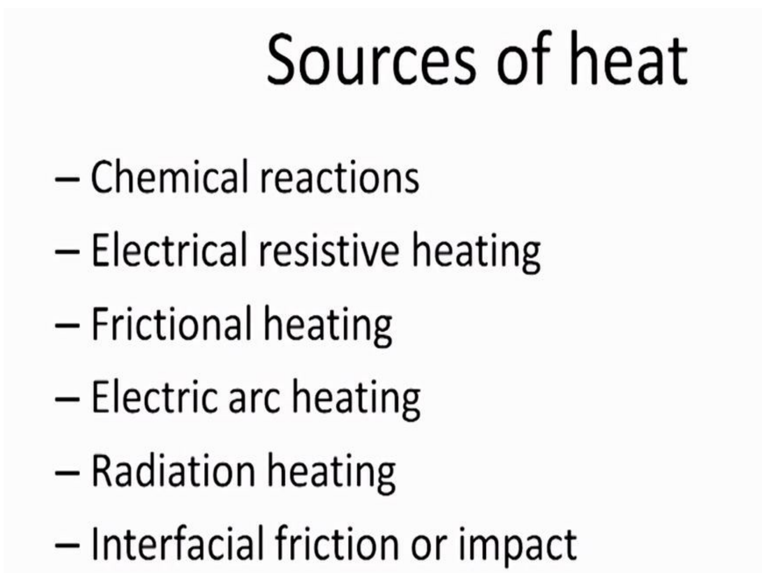

So, the heat can be generated for the welding purposes for the joining purposes through different ways. And these are the common sources for heat, which is used for and developing the heat or applying the heat during the joining process. One is chemical reactions, chemical reactions basically involved in chemical interactions between either gases like a fuel gas and oxygen or the chemical interactions between oxides and the reducing agents like aluminum oxide or iron oxide and the copper oxide interacted with the aluminum or the magnesium kind of agents.

And these reactions occur through the exothermic, these reactions are exothermic in nature so they develop lot of heat, increase the temperature of the faying surfaces for developing for producing the molten metal at the faying surfaces. Electrical resistance heating basically uses the electrical resistance heating I Square R t. The heating principle for developing heat at the interface, so that the softening of the surface layers can be achieved for developing the bond.

Frictional heat involves basically use of the frictional heating principle, where the coefficient of the friction normal load and the velocity between the members involved plays a big role in developing the frictional heat. Electric arc heating, basically uses the welding current and the kind of arc voltage, which is being used for developing the heat. So, VI determines the power of the arc and governs the amount of heat being generated and the radiation heating.

It uses the electron beam or the laser beam, which over which are focused over a small area and will be impact and by activation of the - and the material is activated through the impact of these radiations to produce the heat and so that helps in melting as well as the evaporation of the material but for the joining purpose mainly the melting is achieved and then interfacial or the interfacial friction and the impact.

Normally impact and interfacial friction like in, ultrasonic welding or explosion welding generates very limited amount of heat but that sometimes helps whatever limited amount of heat is generated that helps to facilitate the deformation of the expertise present at the surface in development of the joint or for producing the metallic continuity. One by one we will be going through the different ways by which heat is generated through these different sources.

And subsequently I will come to that how the energy density has will do the different sources play a bigger role in developing them. Sound weld joints or the way by which the joint performance is affected by the heat input.

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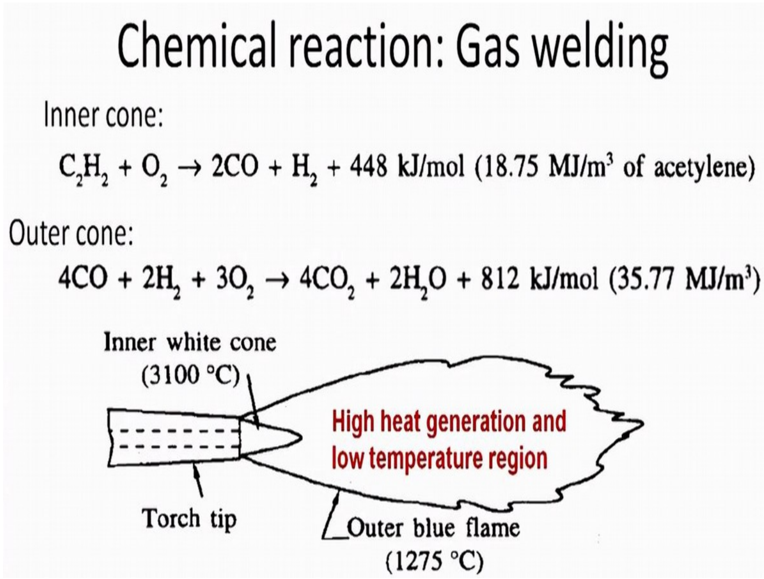

So, here if you see the chemical reactions in the game, in chemical reactions, which are involved in heat generation basically gas welding and thermite welding, so like the acetylene is used along with the mixture of the oxygen means a mixture of acetylene and oxygen is used they interact and produce lot of heat and since whenever the fuel gas and oxygen mixture is born, it produces basically 2 or 3 cones depending upon the relative amount of the fuel gas.

And the oxygen like say here the 2 cones are produced whenever flame is produced with the combustion. There is an inner cone and there is an outer cone. Inner cone involves certain kind of reactions, generates the limited amount of the heat but since this is small and well covered with the high temperature zone of the outer flame region. So this zone experiences the maximum temperature of about 3100 degree centigrade, while the outside region generates a lot of heat as compared to the inner cone.

But, since it is exposed to the atmosphere and surface area of this flame is also very large for despite of having generation of the more amount of heat in this zone, the temperature is low and it offers the blue, outer blue flame in the outside.

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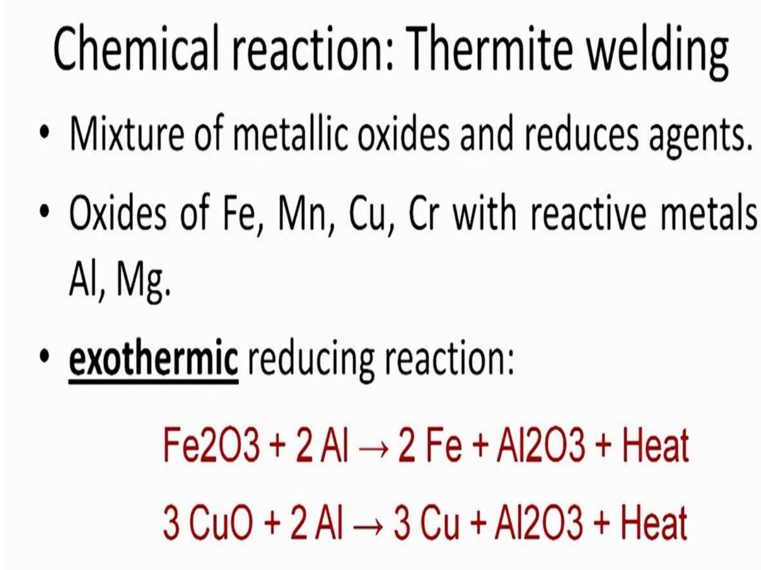

While in the chemical reactions involved in the thermite welding, they use the metallic oxides and the reducing agents in form of like say, the magnesium and the aluminum these oxides of say iron, manganese, copper, chromium etc. with reactive metals like aluminum and magnesium. So when they interact, they produce a lot of heat and that facilitates the melting of the mixture and the molten metal is then fed in between the faying surfaces for developing the joint between the members being joined.

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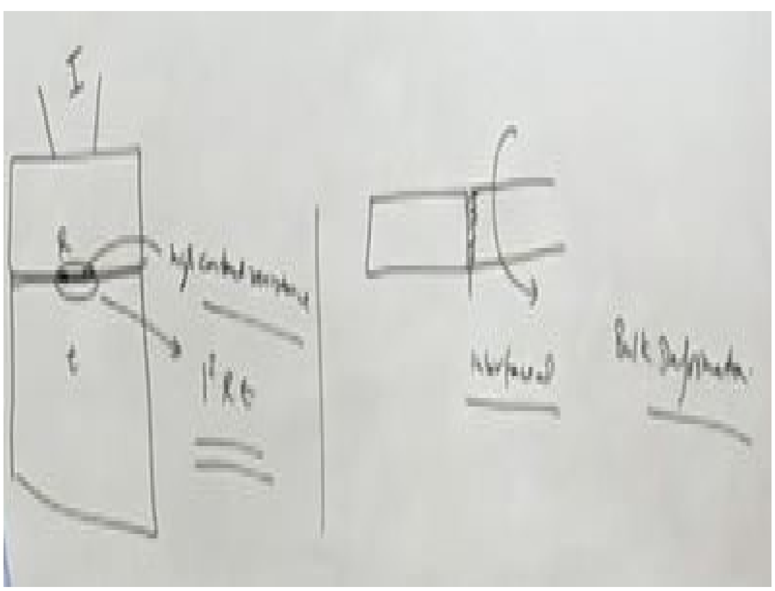

Then we have electrical resistance heating this simply uses the principle of the high contact interfacial resistance, say, these are the two components being joined, so here of course, they will have the contact through the peaks and valleys present at the surface and here if we supply current through the electrodes, so the high contact resistance at the interface lays a big role in developing the heat.

So, flow of the high current and the high R value for a certain time leads to the development of very high magnitude of the current here and very high magnitude to the heat, which is generated. So this heat is basically used for the softening of the interface and sometimes a little bit melting also takes place. So I Square R t heating is involved with the t, t is the time for the flow of current, R is the contact resistance and then here, I is the welding current, which is fed.

The current value is too high and the time is in milliseconds and the current is in thousands of the ampere. So, this principle is used for the generation of the heat in all resistance with base welding processes like the spot welding, seam welding, projection welding etc.

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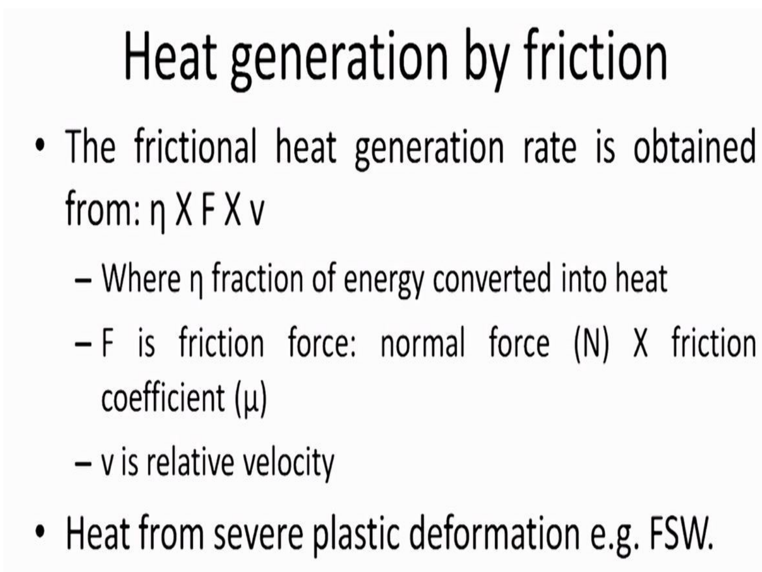

Then the friction welding, friction welding is used in different ways, in the different forms one is the simple friction welding, where the one end is kept fixed and the another is moved and like say it can be read translatory or the rotary movement and this rotational movement under pressure generates the frictional heat and this frictional heat generated can be given through the Eta multiplied by frictional force multiplied by the velocity.

So where an Eta is the fraction of the energy converted into the heat and F is the friction force obtained from the normal force multiplied with the friction coefficient and R is the relative velocity. So, the frictional heat is one thing but in some of the friction based welding processes interfacial deformation also takes place. So, they are two types of deformation. One is interfacial, which is typical in the friction welding and another is bulk deformation, which takes place in case of the friction stir welding.

So this bulk deformation, we know that whenever metal system is deformed, so part of the energy consumed in deformation is also converted into the heat. So, heat coming from the deformation also contributing softening of the metal, so basically say, that the heat from the severe plastic deformation is also generated in the friction based welding processes apart from the interfacial friction heat.

In addition to this, radiation based processes like laser and electron beam. The beams are directed over a very smaller area and very high energy density is produced and that helps in melting of the faying surfaces in a very short period, over a very small area and that makes the melting very efficient and effective for the joining purpose.

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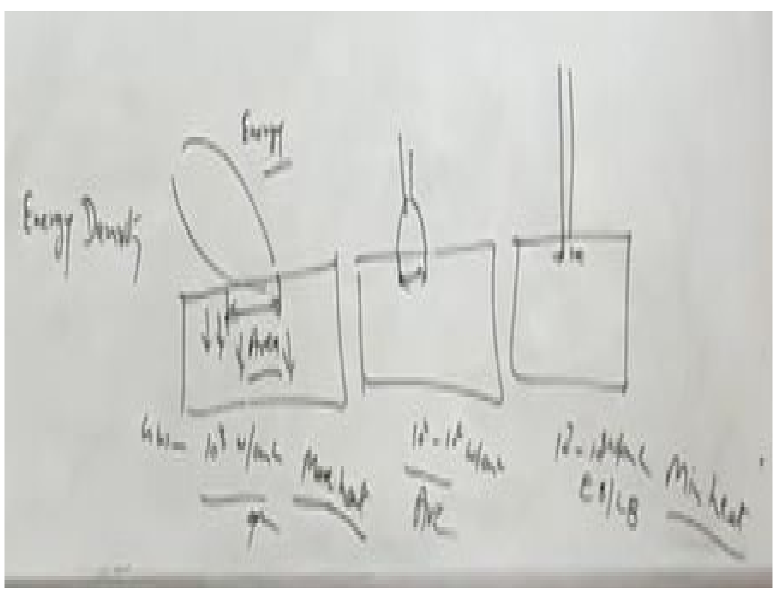

So, if the different welding processes are compared in terms of their energy density, energy density or the power density related with the welding process can be, first we have to see what it is, like say, there is a flame like in gas welding, which is applied over a large area like this or there is a welding arc, which is applied further for a smaller area as compared to the gas welding and then if we see that the laser beam or electron beam, it is applied further over a smaller area.

So there are two aspects, one is the energy associated and another is the area over which it is applied. So the ratio of these two helps us to get the energy density, so more energy applied over a smaller area results in the changing energy densities associated with the different processes. So depending upon these kind of process, which is being applied, gas welding applies limited energy over a larger area.

And that is why the energy density associated with the gas welding is very limited, say, like 10 to the power 3 watt per centimeter square. While in case of the arc welding it may range from say 10 to the power 4 to 10 to the power 6 watt per centimeter Square. It may be further higher for like 10 to the power 7 to 10 to the power 8 watt per centimeter square for laser electron beam and the laser beam welding processes.

So this is for arc, this is for gas, these are the general boundaries as far as the different welding processes are concerned and broad grouping up the processes are concerned. So whenever heat is delivered a larger area of course it will be dissipated to the base metal in larger quantity, it will take longer time to reach to the melting point and then to facilitate the diffusion. Smaller is the area lesser will be the heat dissipated to the base metal, underlying metal of the base metal and then lesser time it will take to fuse.

So amount of heat actually to be delivered for the fusion purpose that keeps on decreasing with the increasing power density or energy density necessary to do. So, this will require maximum amount of heat for fusion purpose and this will require minimum amount of heat for fusion purpose and in between it will be for the arc. So heat, the amount of heat required for the fusion purpose.

So that the joint can be made varies with the energy density and that heat, that amount of the heat, which is required for the fusion purpose significantly affect the joint capability or the performance of the joint that is what we will see.

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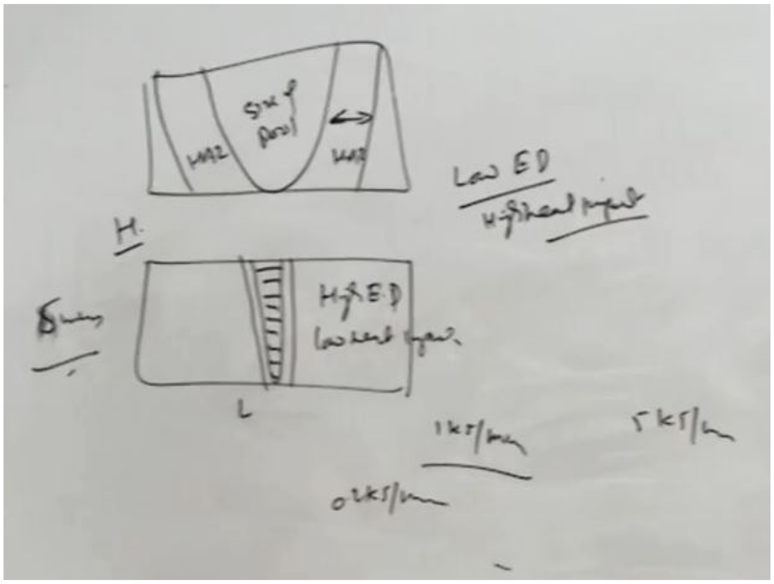

Now that, if the amount of the heat required changes how the characteristics of the joint change. So if we will see here, if the amount of the heat, say, it is in 1 Kilo Joule per mm because our heat source keeps on moving during the welding, so if the heat delivered 1 Kilo Joule per mm or it is 5 Kilo Joule per mm or it is just 0.2 Kilo Joule per mm then there will be lot of difference in terms of the characteristics of the joint, which will you produced, say, this is 3 mm or this is a 5 mm sheet being welded.

So if you work with the low heat input, then the joint size means the weld size is very small and related heat affected zone size is also very limited. But if you work with the somewhat higher heat input, then the size of the weld will increase and associated the size of the heat affected zone will also increase, so width of the heat affected zone and the size of the pool, both will increase. These two things play a big role as far as welding is concerned.

This kind of the joint and the pool is obtained when the heat input or heat input is high and low energy density and high heat input this is what happens in case of the low energy density process like gas welding or simple solid metal arc welding processes. And high energy density processes, they offer very small size and the high energy density process require very limited heat for the fusion purpose.

So low, these are the low heat input process, they produce very limited size of the well pooled and the heat affected zone is also very limited and because of these differences only we find that these the quality of the joint, the load carrying capacity of the joint and the other characteristics of the joint with higher energy density process much better as compared to the low energy density processes. So that is what we will try to see here.

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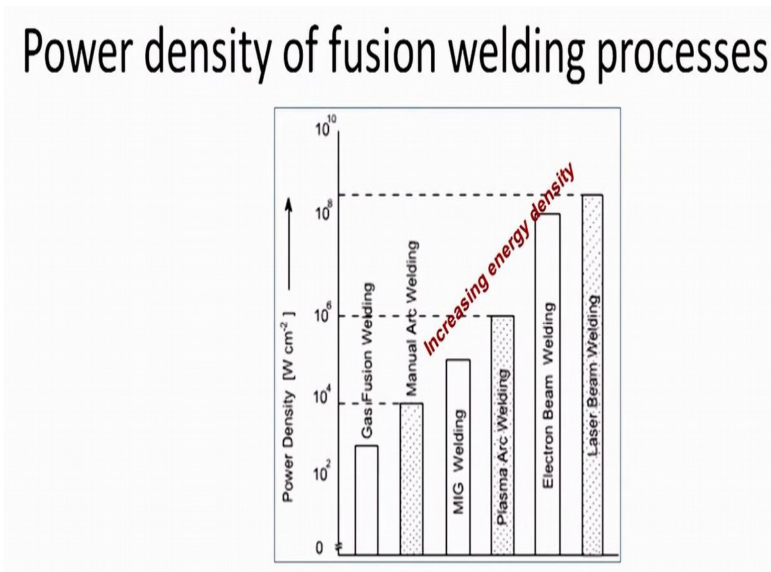

The same thing can be seen here like the gas welding like about 10 to the power 3, for manual metal 10 to the power 3 watt per centimeter Square. Here for manual metal arc welding 10 to the power 4 watt per centimeter Square, for MIG welding 10 to the power 5, for Plasma 10 to the power 6, for electron beam 10 to the power 7 or 10 to the power 8 for the laser beam welding processes.

These are in ascending order of the increasing energy density, higher the energy density lower will be the heat input, which will be required for the fusion purpose. So this is what we can understand from this diagram also, so where in like, if the energy density is high, the time required for delivery of the energy is very less for the melting purpose.

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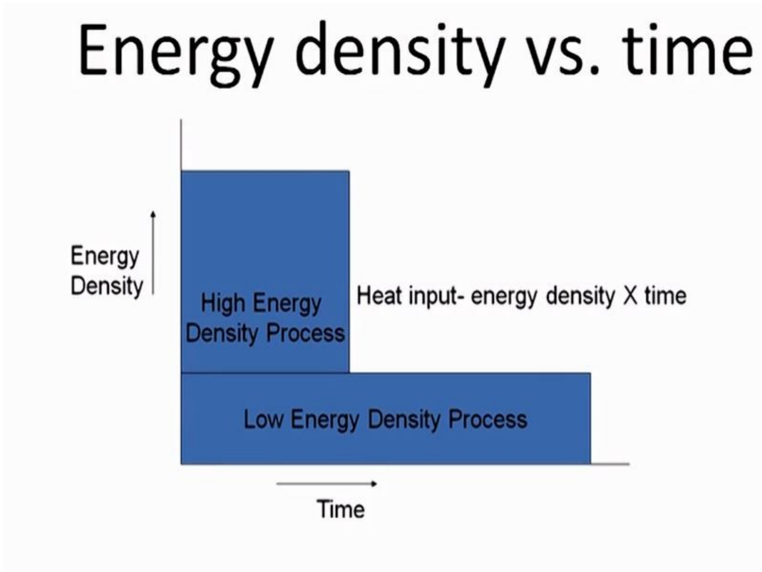

When the energy density is low, time required for applying the energy for the fusion purpose is very long. Whenever we have to apply the source of heat for longer period, we know that the heat will continue to dissipate to the base metal and the amount of heat requirement for the fusion purpose will also keep on increasing. But that is not so in case of the energy density process.

Because the amount of heat actually required for melting of a unit volume of the metal is fixed and which is quickly delivered by the high energy density process and very less amount of heat is dissipated to the base metal and that is why the time required for achieving the fusion is stated in the higher energy process very limited. So this is what we can say energy density multiplied by the time or directly related and this will govern the amount of heat being delivered.

More heat to be delivered for this category of the processes as compared to another high energy density processes. Now, we have to see that why in which way it is important to see the energy density and how does it affect the welding as a whole or the joining process as a whole.

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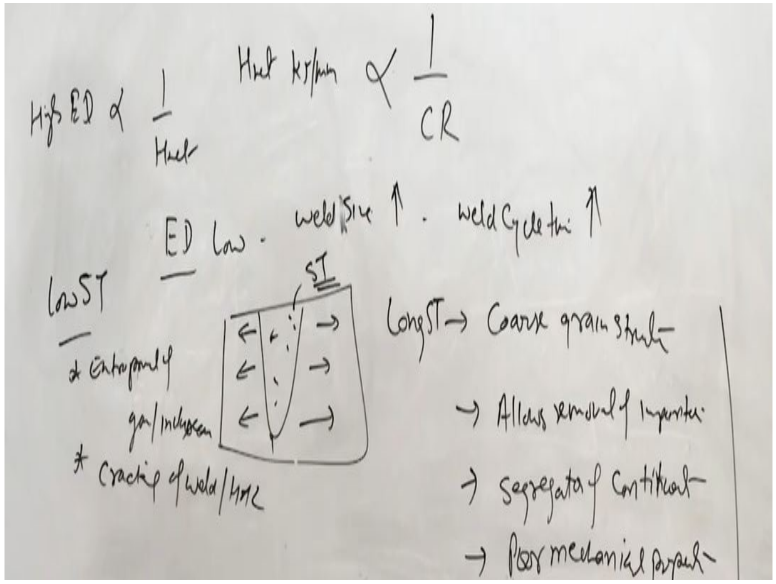

So we will see that when the energy density is low, so the weld size is big and weld cycle time is long, so this delays the production processes a whole, the weld size is large, longer solidification time so it delays the weld cycle. When the energy density is low, this is one factor. Another is the weld pool size is big, when the energy density is low, weld pool size is big, so lot of heat is to be dissipated to the base metal.

So our solidification time is large, so long solidification time allows each of the constituents in the weld to grow to the large extent, so it results in the coarse grain structure because lot of time is available for the grains to grow, at the same time it allows the impurities to come up to the surface like if the gases are in present in the weld, then it will come up to the surface if the inclusions are being formed then they will get enough time to float over the surface.

So allows removal of impurities in form of the gases and the inclusions. At the same time, it will result in the segregation of the constituents means if the alloying elements in the molten pool are of the different densities, then they will have a lot of time to get segregate either to settle down or to float over the surface. So, it will increase the tendency for the segregation purpose.

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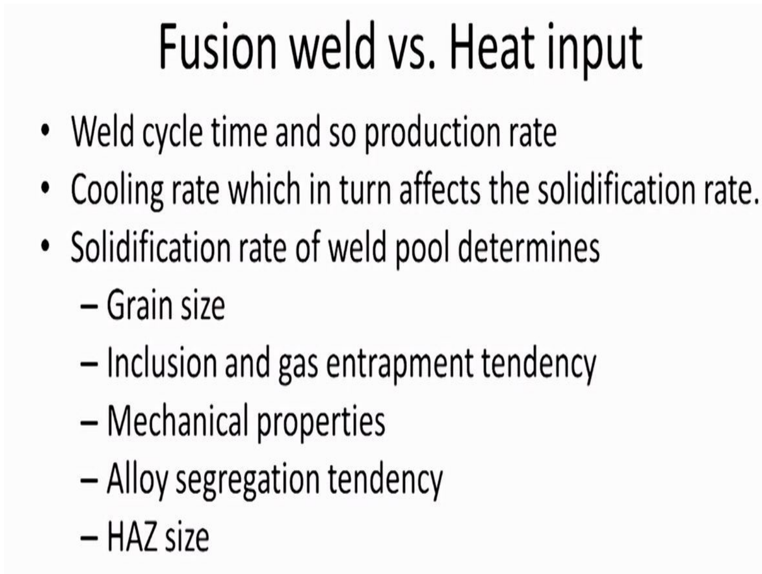

And then we will see that at the same time if the course grain structure is being formed then it will result in the poor mechanical properties. So, the solidification time is actually linked with the number of things and solidification time is related with the heat input. So, basically the heat input in, say, Kilo Joule per mm directly affects the cooling rate, it is inversely proportional. Higher the heat input, lower the cooling rate.

So, if the energy density, on the other hand, we will see, the higher energy density, lower will be the action it required. So, these are the two again inversely related higher energy density, the heat input will be low or if the energy input is low, heat input will be high. So, these are the inversely related. So, on the other hand it is not always good to have the longer solidification time, it is not always bad.

Because longer solidification time helping to remove the impurities in form of the inclusions and the gases, but it is adversely affecting in form of like coarse grain structure and the increased segregation tendency. On the other hand, if the solidification time is very less, then it will result in very low solidification time is also not very good because entrapment of the gases, inclusions will be promoted.

This is one thing and it can lead to the cracking of weld and as a jet especially in case of the steels are of the hardenable steels. So sometimes intentionally the preheating is done, so that cooling rate can be reduced and solidification time can be increased. So these are the different aspects related with the heat input and amount of heat input is the function of the energy density associated with the process.

If the energy density is high, heat input will be low. Low heat input causes the higher cooling rate and higher cooling rate will have its own effect as compared to the low cooling rate conditions, so effect on the joint performance and other soundness of the joint that is what we will see in the subsequent slides.

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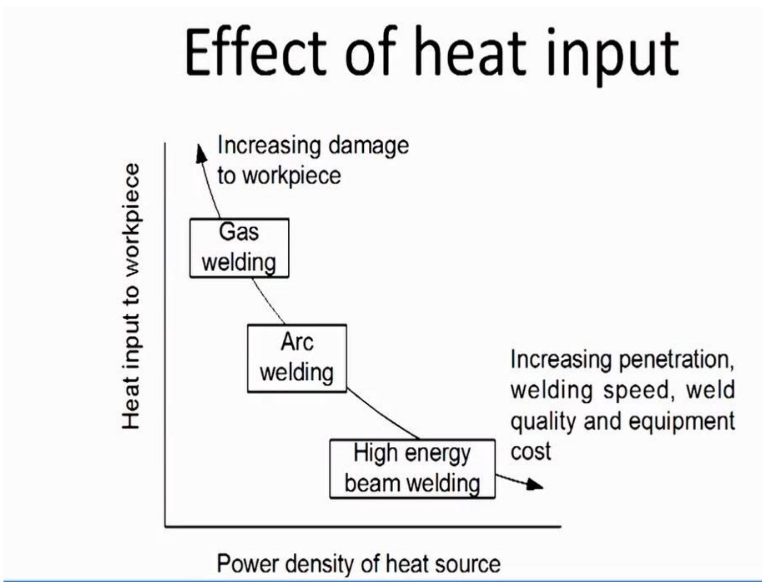

Here we can see that as the power density increases, the amount of heat to the work piece decreases. So if you see the power density of the heat source for gas welding heat input is high, power density is low and for arc power density somewhat high, energy density is somewhat heat input is low to the work piece for developing the joint and when energy density is high, power density is further high.

So if we see the effect on the welding with the change of the energy density. If we go on the low power density or energy density with the low power density heat source then it will increase the heat input, which in turn will increase the damage to the work piece. And on the other side, when we work with the higher power density or energy density we will see that high energy density process will result in the greater penetration higher welding is in good quality weld joint, so this is how we can see that the adverse effect of the heat input on the work piece is more when we work with the low power density welding processes as compared to the case when you work with the higher power density processes.

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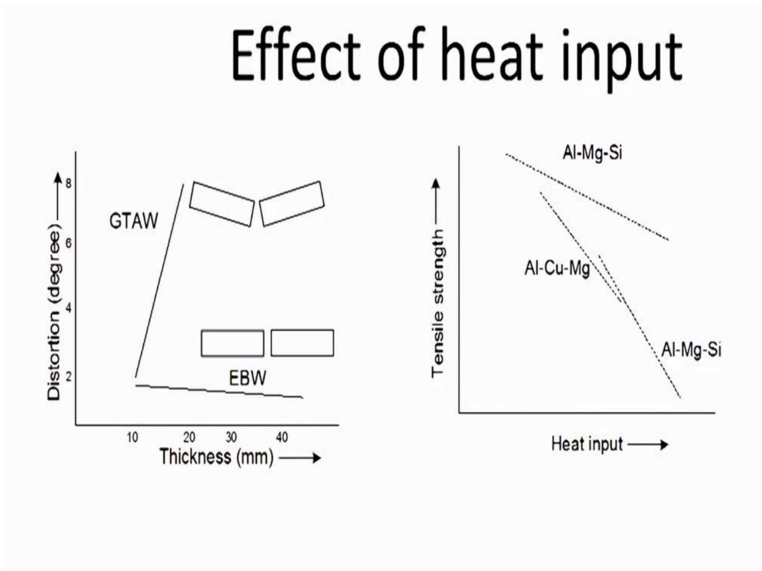

This is what we can see from this diagram also like the electron beam welding process does not cause, I mean, this is the distortion in y axis and this is the thickness of the plate. So in general, increase in thickness increases the angular distortion especially in case of the Gas tungsten arc welding but there is no major change as far as the electron beam welding is concerned. High energy density process will be supplying very limited amount of the heat to the weld.

And so the amount of the kind of expansion and contraction experienced by the base metal is very limited and so it causes with the minimum or negligible distortion to the work piece. Similarly, the heat input also effects the tensile strength of the weld joint especially in case of the precipitation hardening systems like aluminum alloys, we can see that in general, increase in heat input decreases the strength of the weld joint.

And this is because the reversal resolution cautioning of the precipitate, all that happens and with the increase in heat input and which in turn adversely affects the strength of the weld joint. So it is very important that the amount of heat being delivered to the work piece is kept as minimum as possible for developing the sound weld joint so that the joint performance is not compromised much.

So in this presentation what we have seen the heat is used for the variety of purposes, there are different sources of the heat, there are different ways by which heat is generated and each kind of the source of the heat offers the different power density and power density has a big role in delivering the different amounts of the heat to the weld and amount of the heat being delivered to the weld for welding purpose affects the joint performance in terms of the mechanical strength, distortion tendency, the size of the weld metal, the structure of the weld joint.

So it is important that heat being delivered to the work piece is kept as low as possible, so that the sound joint is made without compromising much of the quality of the weld joint and without adversely, without much adversely affecting to the base metal. So thank you for your attention. In the next presentation, I will talk about the way by which, why the weld pool being formed should be protected from the environmental gases.

And what are the various approaches to protect the weld pool so that the sound weld joint can be made which are free, from the porosity and inclusions. So see you in the next lecture. Thank you for your attention.