Joining Technologies of Commercial Importance
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Lecture - 06
Principle of Fusion Welding Processes: Gas Welding

Hello, I welcome you all in this sixth presentation on the subject joining technologies for the metals and this presentation will be based on the principles of the fusion welding and we will be starting with one welding process which is called gas welding, so the different aspects of the gas welding process we will be talking about.

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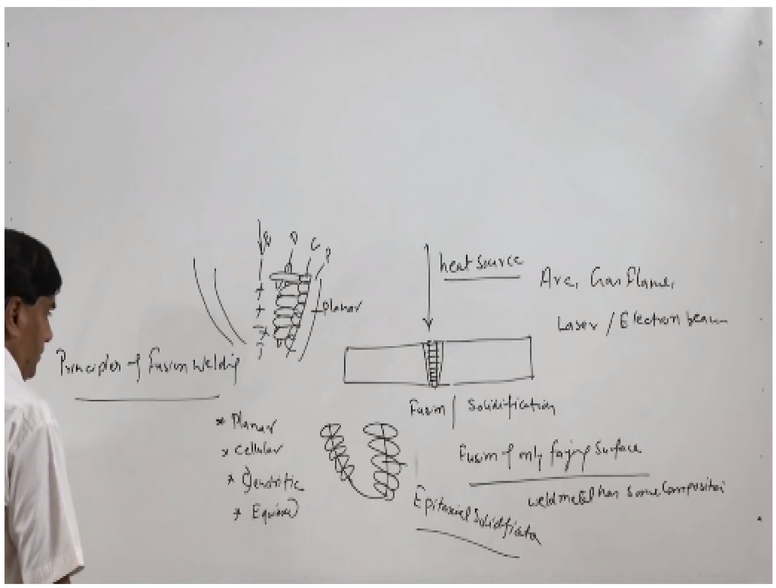

So basically the principle of fusion welding that is what we have to talk. Like the components to be joined after proper cleaning of the faying surfaces using suitable heat source, heat source is applied in form of arc or gas flame or like say the laser or electron beam and likewise any other heat source, so this will be directed onto the surface, faying surfaces of the component primarily to bring them to the molten state.

And so that the metallic continuity between the components to be joined is obtained after the solidification. So the two things are important, the phosphatase fusion and thereafter the solidification which will result in the metallic continuity from one end to another. Now, if the fusion of only faying surfaces is taking places, then the weld metal composition is considered to be almost as same as that of the base metal.

So, in this case, when fusion of the only faying surfaces is achieved for developing the weld joint, then the weld metal has same composition as the base metal and in this situation, whatever the partially melted grains are there of the base metal on that solidification starts with their direct growth, no nucleation is needed, so this is how the growth of the partially melted grains start without the need of any nucleation.

Now depending upon the kind of the solidification conditions here normally the different kind of the grain structures are observed and this kind of solidification where that growth starts onto the partially melted grains is called epitaxial solidification. This happens when the composition of the weld metal is similar to the base metal, but if the composition is different then the nucleation and the growth mechanisms are involved for completing the solidification.

Normally, the first the columnar grain is normally 3 or 4 types of grain structures are observed, one is the plainer which is very plain next to the fusion boundary, then we normally observed cellular zone then dendritic and then equiaxed structure. So normally first is the plainer, second is the cells like this, third is in form of the dendrites having the dendrites like this.

And then equiaxed grain structure at the center of the, likewise the similar kind of structure is obtained from the other side, so plainer, cellular, dendritic and equiaxed grain structure is normally observed at the same. It is always preferred to have the equiaxed grain structure and therefore to achieve this equiaxed grain structure completion modifications are carried out. But if the weld metal composition is different from the base metal.

Then the first nucleation on the fusion boundary takes places thereafter the growth occurs, so that is typical nucleation and the growth modes are involved, steps are involved for completion of the solidification related with this only since we have supplied heat for the fusion of the faying surfaces.

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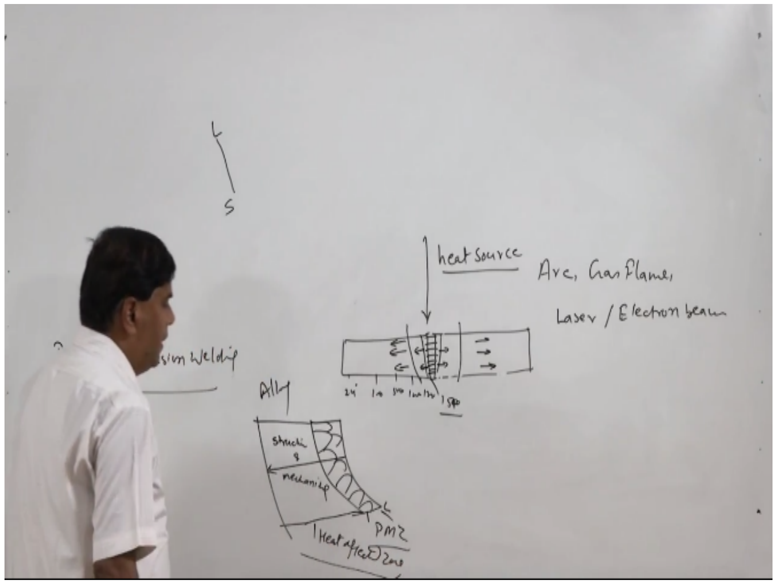

So due to the thermal conductivity of the base metal, some of the heat is transferred to the underlying metal below the fusion boundary and this heat transferred to the base metal increases the temperature of the metal to the different degrees, say here it may be 24 degree, then 100 degree, 500 degree, 1000 degree likewise say 1200 say 1500 in case of the steels or 1540 degree centigrade.

So as we approach towards the fusion boundary the temperature keeps on increasing and so the distance up to which temperature of the base metal is above the melting point that is completely brought to the molten state and thereafter sometimes if the metal is pure, then the boundaries clear, but if the metal system is an alloy, then we will have 1 solidus and 1 liquidise and there is a temperature difference between the two.

Wider is the solidus and liquidise then there will be, so this corresponded to the liquidise and then there will be a solidus line. And between these 2, we have the 2-face zone where partial melting of the grains will be taking place, especially at the boundaries, so this is called partial melting zone. This is found next to the fusion boundary and thereafter, this is a very much part of the heat-effected zone.

And thereafter all that distance up to which when the metal is heated by the heat supplied is affected like say this is the fusion boundary. This is the partial melting zone, so all that distance up to which the metal is subjected to the variation in structure and mechanical properties, all that zone is termed as heat affected zone. In the welding, the heat affected zone is 1 which is in an integral part of the fusion welding and it cannot be eliminated.

So efforts are always made to control the size of the heat affected zone.

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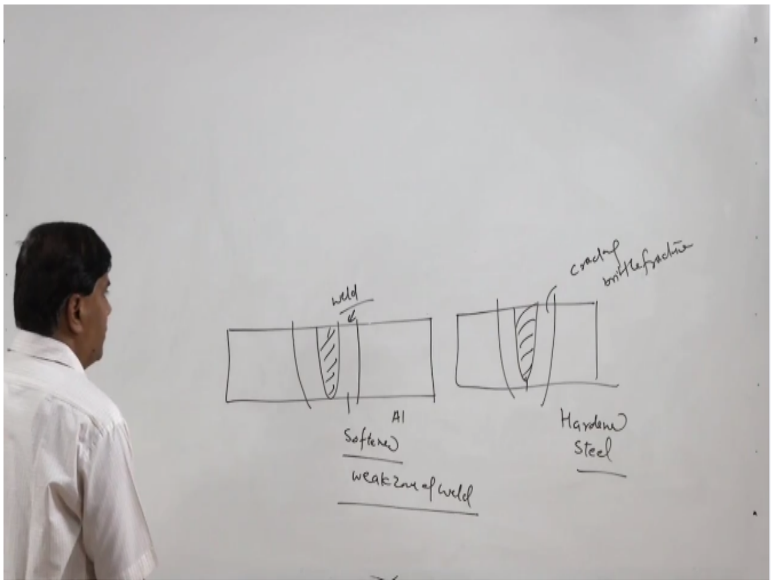

Now we will see the different metals respond to the heat in different ways especially in the heat affected zone, say this the weld area and now, some of the metals like aluminium, this zone after the heat due to the heat of the welding, this usually gets softened. So the softening of the HAZ is observed and sometimes it forms the very weak zone of the weld and failure is localized, failure of the weld joint is localized in the heat affected zone.

On the other hand, if it is a steel then the development of the weld zone and thereafter narrow zone which is affected by the heat, it gets hardened in case of the hardening steels. So this hardened zone becomes sensitive for cracking as well as the brittle fracture in which way the heat affected zone will respond that depends upon the kind of metal system being welded and this heat affected zone cannot be eliminated.

Because heat always gets transferred from the fusion boundary to the base metal due to the thermal conductivity, so efforts are always made to reduce the size of this heat affected zone because we do not have any control over the heat affected zone, only it is size can be reduced. So, efforts are made in order to reduce the size of the heat affected zone.

So either the hardened zone in case of the hardenable steel or the softened zone in case of the like precipitation hardenable aluminium wise or work hardened aluminium wise can be achieved, so sometimes we have control over the weld metal in the sense that the weld metal composition can be adjusted as per requirement by using the suitable filler metal or suitable composition of the electrode in case of the consumable arc welding processes, but heat affected zone cannot be.

We do not have any control over the heat affected zone in that sense because whenever heat is applied it is formed only therefore efforts are made in order to reduce the size of heat affected zone so that advance effects related to the fusion welding can be reduced. So those processes where the amount of heat required for the fusion is more, size of the heat affected zone is also found to be more. This is what we have seen in case of the heat sources for the welding.

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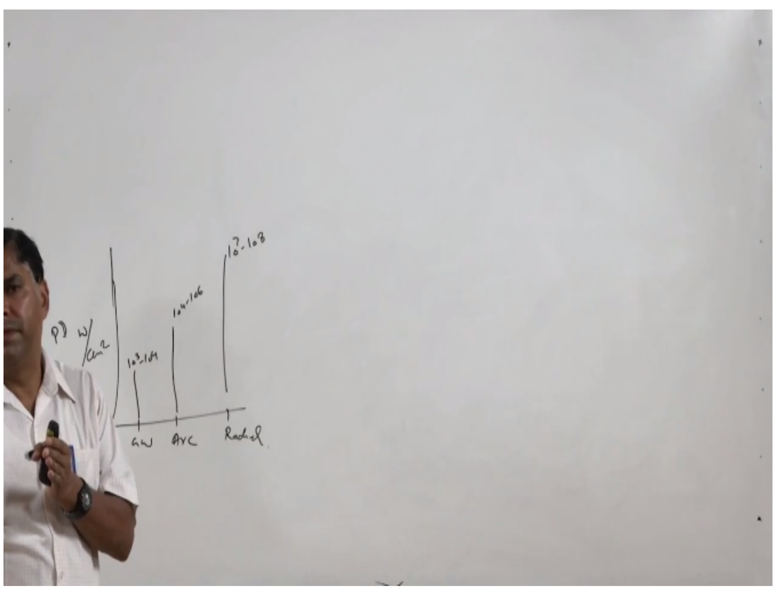

I have told in the last previous lecture, I have told you that the guess welding, arc welding and like say the radiation welding like laser and all these are in increasing order of the power densities, like say 10 to the power 7 to 10 to the power 8, 10 to the power 4 to the 10 to the power 6 and like say 10 to the power 3 to the 10 to the power 4, power density in terms of watt per centimeter square.

So higher is the power density, lesser be the amount of heat that is to be supplied and so that will limit the size of the weld zone and that will also limit the heat affected zone width. So if the heat affected zone width is reduced that in turn will reduce the adverse effects related to the formation of the heat affected zone.

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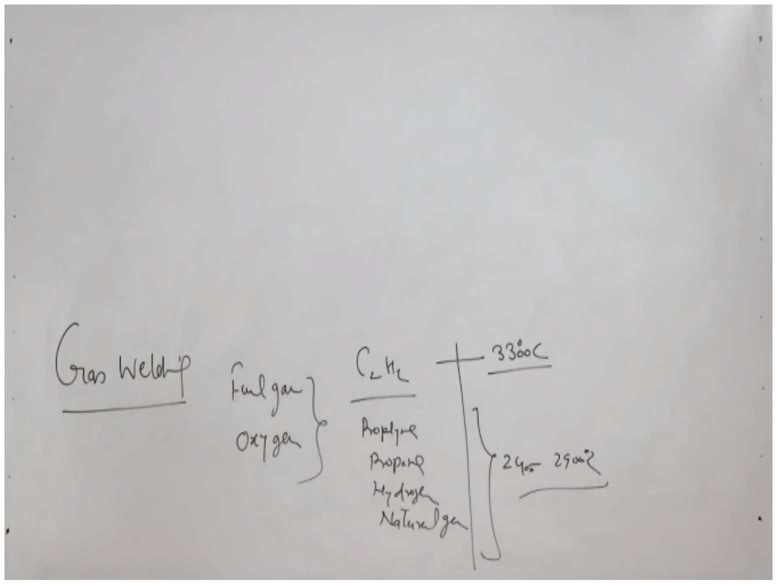

Now coming to the gas welding process and its principle, so the gas welding basically uses 1 fuel gas and usually oxygen is used for achieving the proper combustion, most common fuel gas is like acetylene, thereafter propylene, propane, hydrogen, natural gas or the other gasses which can be used as, which can be used as fuel gas for the gas welding purpose. However, the most commonly used gas is the acetylene.

Because it produces the highest temperature of the flame. While the temperature observed in case of the other gasses it may be very say 2400 to 2900 degree centigrade and this lower temperature adversely effects the process capability or the performance of the process in the sense that it takes long first to start the welding because it should reach to the flash point or it takes very long to start the process thereafter the welding.

So the other gasses are not that effective in terms of the kind of the conditions which are produced by them during the welding.

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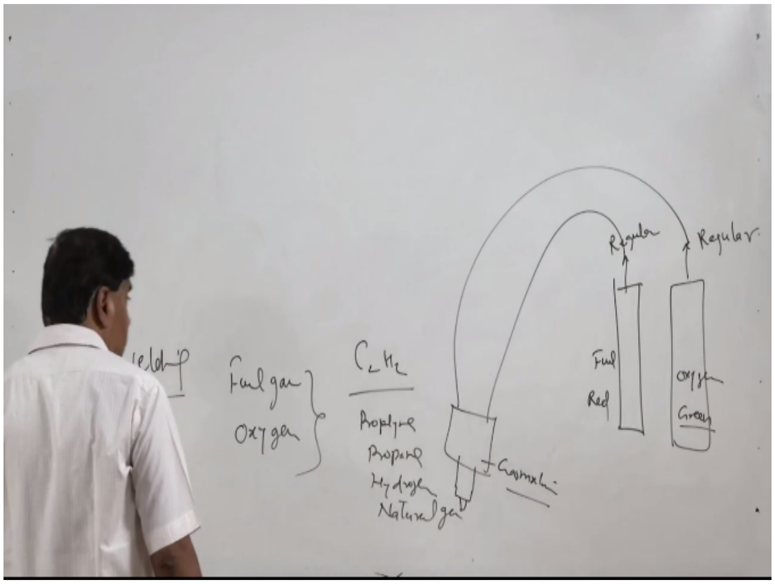

So, whenever normally like say we use one cylinder for the fuel gas and another is used for the oxygen which is normally green and this oxygen cylinder is normally coded like with the green colour and this is the red colour. There is a regulator, with the both cylinders regulators are used which will bring down the pressure of the oxygen or the acetylene to the normal working pressure and then these are connected through the proper mixtures.

And then it is fed through the torch. Now torch will, here this gas mixture will be coming out and here using suitable lighter or igniter the gas flame is generated. So the important thing is about the gas, the kind of the gas flame which is formed in case of the gas welding because that affects the performance of the welding as well as its capabilities.

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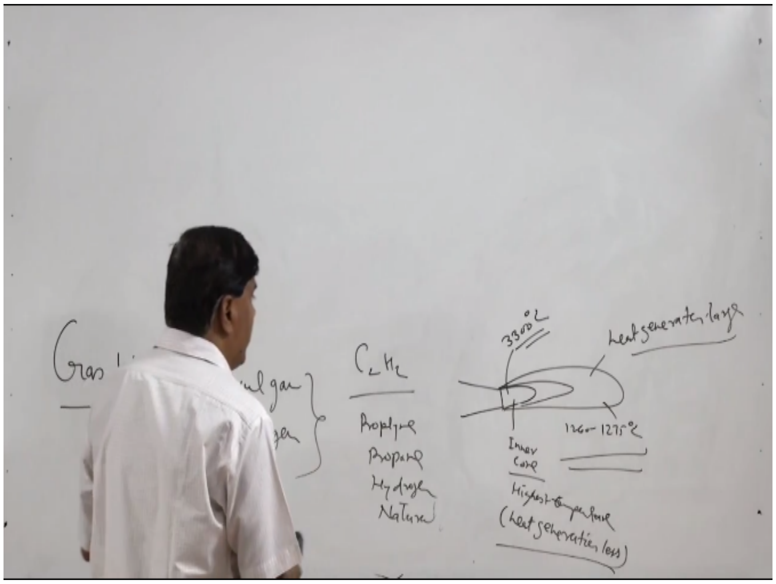

The typical flame which is formed in the gas welding, it has like say this is the inner cone and this is the outer cone. There sometimes a third cone is also observed. So this is called inner cone of the flame, it offers the highest temperature. However, amount of the heat generation in the inner cone is less, heat generation is less, this is what we have seen earlier in case of that how the chemical reactions are used for producing the flame, producing the heat using the fuel gasses and the oxygen.

So here heat generation is less, but since this zone is a small in size and it is covered with the high temperature gasses, so that would be temperature in this zone is high and this can range like say 33,000 degree centigrade in case of the oxyacetylene gas welding process. While the temperature of the outer flame is somewhat lower, it is 1260 to 70, 5 degree centigrade; however, the amount of heat generated, heat generation in the outer flame is much large.

But still since the surface area of this flame is more and it is exposed to the atmospheric gasses, atmospheric air, so because of these two reasons the temperature rise in this outer flame is limited.

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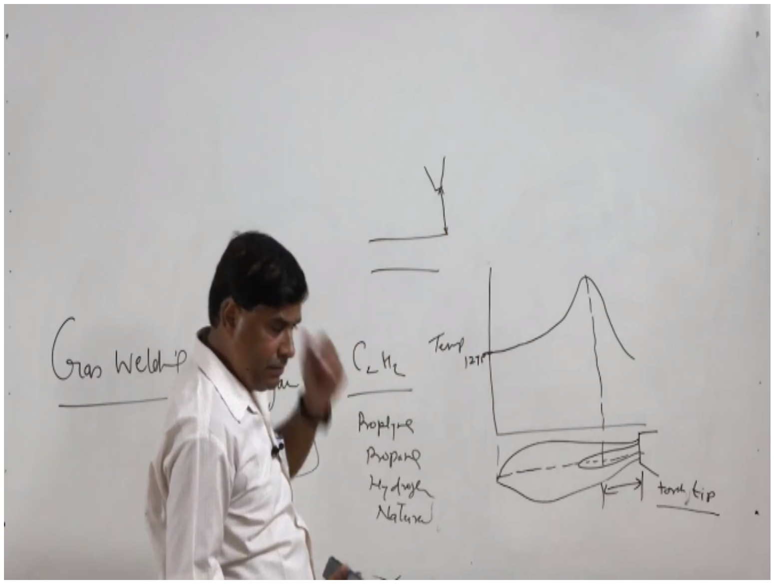

And if we try to plot the variation in temperature as a function of the distance from the flame tip towards the inner cone than that is what we can see from this diagram wherein, like say this is the x-axis and y- axis showing the temperature of the flame, so here say this is our outer flame and this is inner flame. So now we can see how the temperature varies, temperature at this and here it is about like say 1275 degree centigrade and then on approaching towards this along the axis of the flame.

This temperature will keep on increasing and then it will reach, thereafter it will start falling down so the temperature somewhere in the middle of the inner cone is found to be maximum and therefore, and this side what we have the torch tip, so big temperature occurs in the inner flame somewhere in middle of the inner cone.

Therefore, efforts are always made in such a way that the distance of the nozzle from the work piece is such that the surface of the work piece is just at the peak temperature zone of the inner cone, so this distance is used to decide what will be the distance of the tip of the torch away from the work piece, so that it is adjusted in such a way that the inner cone is at the surface of the work piece in order to increase its melting capability. This is the purpose of showing this plot.

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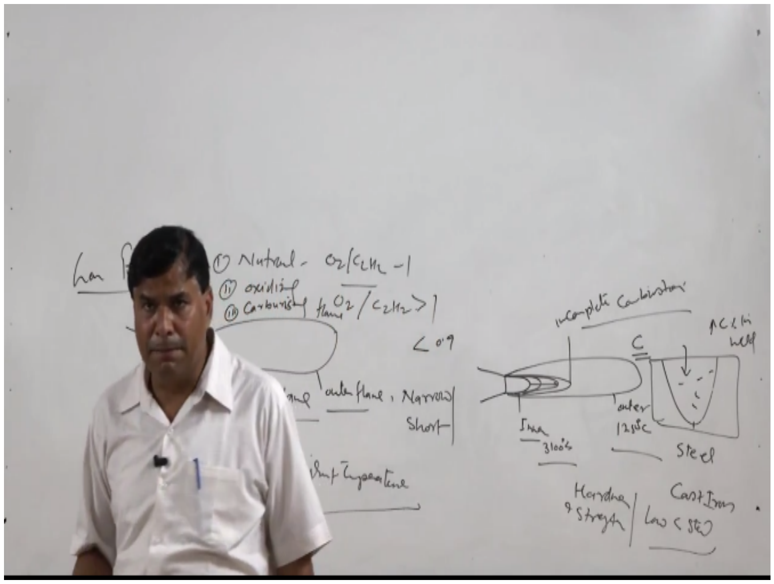

Now we will see with structure of the flame changes and there are various features related to the flame of the gas like this is the nozzle, here we may have very sharp inner cone and then outer one like this, so this one is for oxidizing flame. There are three types of flame which are commonly observed like a neutral when oxygen and acetylene ratio is 1 and the 2 is oxidizing flame when the oxygen is more than actually required for complete combustion

So this ratio is not really more than 1 or 1.1 and when the ratio is reversed like this ratio is less than 0.9 or less than 1, where acetylene is more than the oxygen in that case we get, third is carburising flame. Carburising flame is whenever it is developed, you will see that one additional cone corresponding to the region where incomplete showing that the amount of the incompletely the gasses are present.

So here we will see this is very, so in this case the outer flame is narrow and short as compared to the neutral and carburising flame, so this is one thing and this is very sharp and short. So sometimes highest temperature is observed in case of the oxidizing flame. When the situation changes like if we have higher percentage of the acetylene, in that case apart from the inner cone one intermediate cone is also observed between the outer and the inner cones.

The inner cone of course has the higher temperature like say 3000 or 3100 degree centigrade in case of carburising flame and outer flame like say the 1250 or 1260 degree centigrade. Third flame is corresponding to the suggesting the incomplete combustion. The incomplete combustion if the acetylene is marginally high, then the feather length is limited like this, with the increasing percentage of the acetylene, the length of the intermediate feather increases.

So the length of the intermediate feather corresponds to the amount of the extra acetylene which is present or the kind of it suggestive about the kind of the excess in the percentage with respect to the oxygen required for complete combustion. This incomplete combustion results in lot of carbon which sometimes gets transferred to the pool, so especially in case of the steels, cast irons, the transfer of the unburned carbon to the weld.

Because in carburising flame have lot of the unburned incompletely burned fuel gasses and these gasses get transferred to these carbon incompletely burned gasses producing carbon which gets transferred to the weld pool and thus increased carbon percentage in the weld increases hardness and strength of the weld especially this is good for low carbon steels but in case of the high carbon steels it may lead to the embrittlement and the cracking of the weld.

So this is what is about the different types of the flames which are formed in case of the gas welding. It is preferred to use the neutral flame wherein complete combustion of the acetylene and oxygen takes place during the welding. Sometimes when high resistance and high hardness is required, low carbonized steels can be welded using the carburising flame also.

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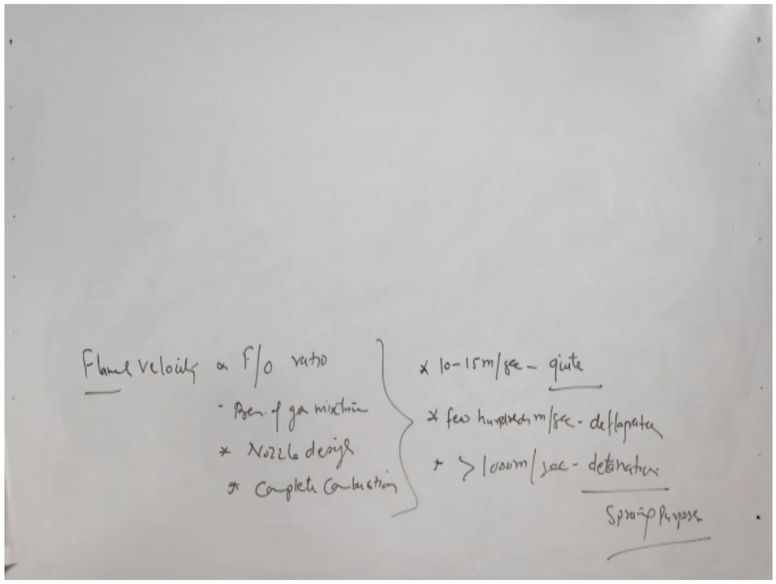

Now depending upon the flame velocity, flame velocity depends upon the fuel and oxygen ratio and the pressure. Pressure of gas mixture being used for the combustion purpose and the nozzle design, etc. and how effectively the combustion, how effective complete combustion is taking place. These are the four factors that will govern the velocity of the flame.

So velocity of the flame when it is in the range of 10-15 meter per second, the flame is called quiet, quiet flame or when it is in few hundreds of meter per second like say 300, 400, 500 meter per second, it is called deflagration flame and when it is greater than 1000 meter per second, the flame is called detonation. This kind of flame is used primarily for the spring purpose or metal spring purpose where even the refractory and ceramic materials can also be used for developing the coatings.

So, now in the case of the gas welding since the protection is not very effective, so there is possibility that a lot of gasses in form of oxygen and nitrogen are present in the weld metal and which will be producing the impurities in form of oxygen nitrites.

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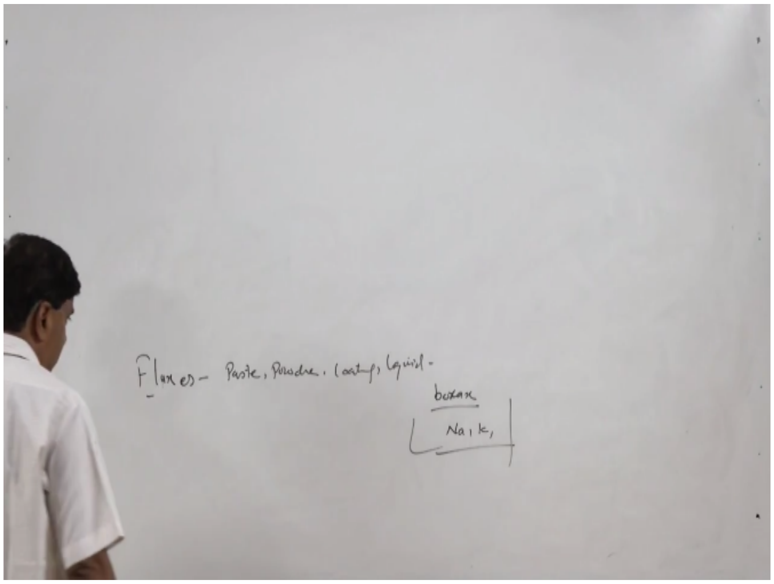

Therefore, to take care of these impurities, normally fluxes in form of paste, powder or solid coatings or liquid is applied over the fraying surfaces before applying the heat and normally these fluxes, the borax is one of the commonly used fluxes. These have like the elements like sodium, potassium, etc. to play an effective role in removing the impurities being formed during the welding.

So now I will conclude this presentation. In this presentation, I talked about the fundamentals related to the fusion welding and how the gas welding, what are the basics of the gas welding with respect to the flame and how it can be used effectively. In the next presentation, I will talk about the different gas welding techniques and how do they affect the properties of the weld joint apart from starting the arc welding related processes. Thank you for your attention.