Advanced Machining Processes
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Module - 07
Lecture - 16
Plasma Arc Machining (PAM)

Welcome to the course on advanced machining processes. Today we are going to discuss on plasma arc machining process. So all of you know this plasma okay. So generally this gas molecules it consist of 2, 3 atoms okay. So when these molecules, gas molecules is heated up to a very high temperature, suppose around 2000 degree centigrade.

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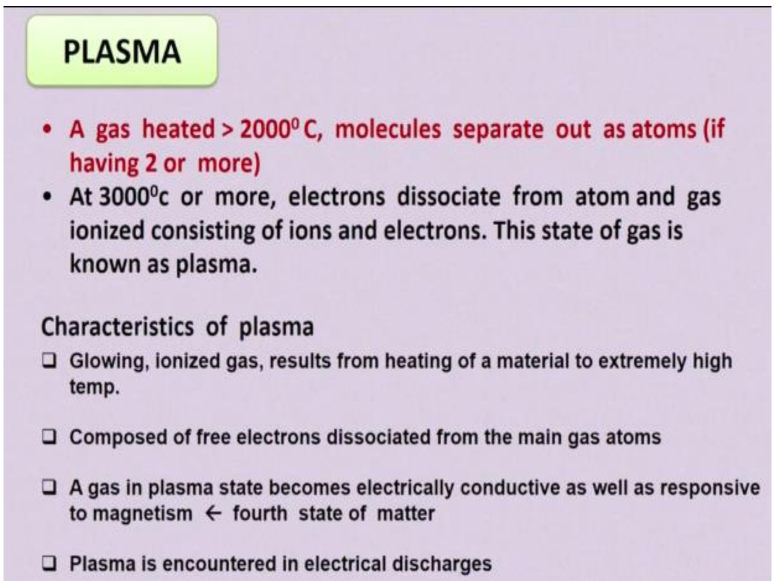

So these atoms actually from the molecules separate out and now when this atoms are heated up to a again to a very high temperature maybe around 3000 degree centigrade this electrons and ions are actually dissociate from the atoms okay. So a gas is heated up more than 2000 degree centigrade molecules separate out as atoms. So having the gas is having 2 or 3, 2 or more atoms and at 3000 degree centigrade or more the electrons dissociate from the atoms and gas ionized consisting of ions and electrons. So this state of gas is actually known as the plasma.

So when this gas is actually heated up again 3000 degree centigrade this electrons actually dissociate from this atoms and this combination of this electrons and ions it is called actually it is a state of plasma state. So characteristics of plasma, it is a glowing ionized gas resulting from the heating of a material to extremely high temperature.

So it is composed of a free electrons and ions from the main gas atoms. So a gas in plasma state becomes electrically conductive. So the property it has a electrically conducting property. Also it, it is responsive to the magnetism. So as this gas in the plasma state it has a conductive property, electrically conducting property, also it responds to the magnetism. So gas in the plasma state it is called fourth state of matter. So plasma is called fourth state of matter. So this plasma is encountered due to the electrical discharges okay. So now how this much of heat is generated from the plasma. So we shall discuss that okay.

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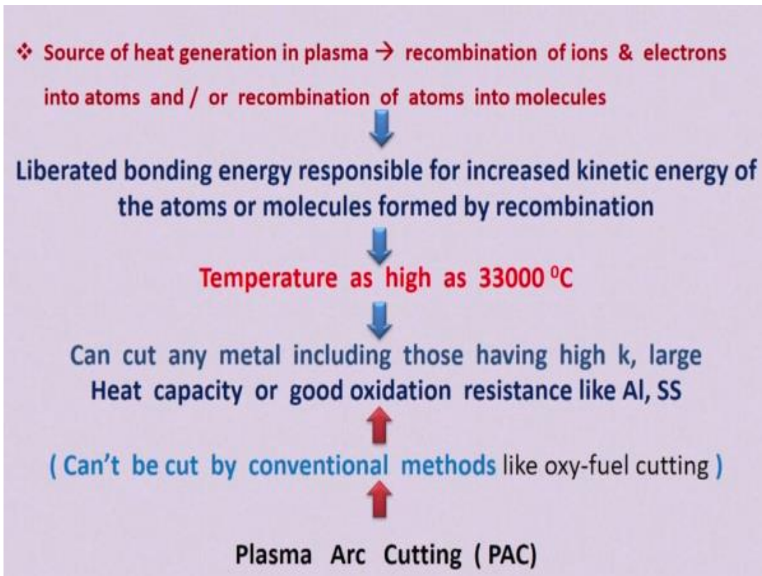

So source of heat generation in plasma. When these separated atoms and electrons, separated ions and also this electrons recombine. So when they recombine, so this recombination of atoms again into molecules, so this liberated bonding energy is responsible for the increased kinetic energy of the atoms or molecules formed by due to the recombination.

So due to the recombination of this electrons and ions into atoms and these atoms into molecules so because of this liberated bonding energy because of this recombination of this ions and electrons into atoms and this atoms into molecules, so because of this liberated bonding energy huge amount of heat is generated.

So this because of this liberated bonding energy which is responsible for the increased kinetic energy of this atoms and molecules formed due to the recombination. So temperature is generated around 33 degree 33000 degree centigrade. So this much of heat is generated. So that is why this temperature rises up to this 33000 degree centigrade. So because of this huge amount of heat is generated, this much of heat can be used for cutting purpose, for any kind of cutting purpose so which is not possible by oxy-fuel cutting, oxy-fuel gas cutting okay. So that kind of thick material can be cut by the plasma arc cutting process.

So can cut any kind of material including those having high thermal conductivity, high heat capacity, and good oxidation resistance. So temperature, this much of temperature is helpful for cutting any kind of materials having high thermal conductivity large heat capacity and good oxidation resistance, materials having good oxidation resistance like aluminium, copper, and then stainless steel. So this kind of materials with higher thickness can be cut by the plasma arc cutting process so which is not possible by conventional oxy-fuel cutting.

So conventionally this thick material is cut by the oxy-fuel cutting operation but when this material thickness reaches to a certain height and also when the material like aluminium and copper they have a high thermal conductivity and high heat capacity. Also some materials have a good oxidation resistance so like stainless steel. So this kind of materials cannot be cut by conventionally by oxy-fuel cutting operation. So that kind of material with high thickness can be cut by the plasma arc cutting operation.

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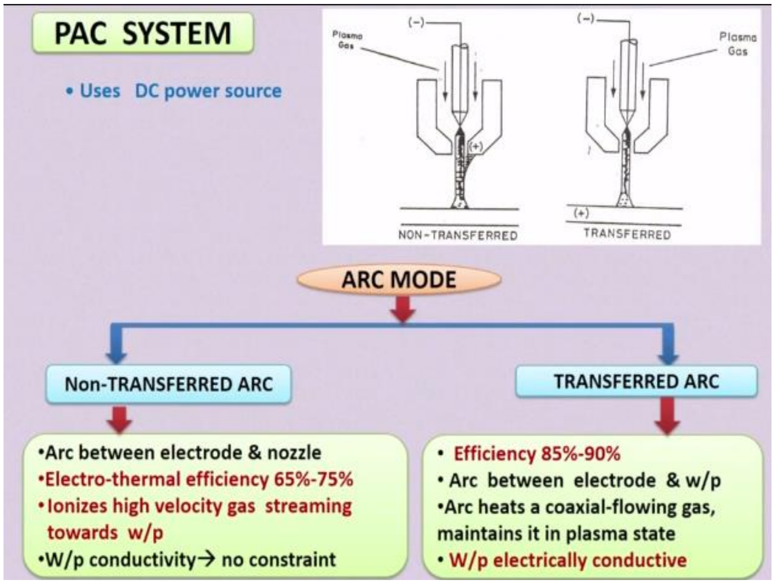

So there are different types of plasma arc cutting operations are here. So there are 2 main configurations are there. So one is the non-transferred mode, another one is the transfer mode. So there are 2 modes of plasma cutting operations are there so one is the non-transfer mode and another one is the transfer mode. So you can see here this is the non-transfer mode of plasma cutting operations here okay. So this is the cathode here. You can see this is the cathode and this is the nozzle here. This nozzle is used as the anode here.

So this plasma gas is flowing surrounding this cathode. So this surrounding this cathode this plasma gas is coming and it is passing, this high velocity plasma gas is passing through this nozzle here. So it is passing through the nozzle. When it is passing through this nozzle, it is ionized, this plasma gas high pressurized, high velocity plasma gas is ionized and using this non-transferred mode any kind of material whether it is electrically conducting or electrically non-conducting, any kind of material can be cut or machined. So this non-transferred arc, arc between electrode and nozzle so this is arc is generated between this electrode and this nozzle.

So here electrode this cathode and nozzle is connected to the anode and electrothermal efficiency of this kind of non-transferred arc is 65 to 70%. So it has a very low efficiency, low efficiency than this transferred mode. So ionizes high velocity gas streaming towards the workpiece when it is passing through this cathode or electrode and the nozzle so high velocity plasma jet is actually here, it is ionizes. So workpiece conductivity is not a constant. So any kind of material, any kind of workpiece material, whether it is electrically conducting or non-conducting, any kind of material can be cut by this plasma, non-transferred mode of plasma arc cutting operation.

But in this transferred mode you can see here this is the electrode here and this positive terminal is connected to the workpiece. So here the main constant is that this workpiece should be electrically conducting material. So this kind of transferred mode can be used only for electrically conducting mode of electrically conducting workpiece material. So here plasma gas is coming surrounding this electrode and while it is passing through this so it is ionized here in this zone it is ionized while it is passing through this nozzle it is ionized.

So electrical efficiency, electrothermal efficiency of this kind of transfer mode, it is higher than this non-transfer mode, here it is 85 to 90% electrothermal efficiency for transferred mode or plasma arc nozzle. So arcing is generated between the electrode and the workpiece and arc heats of this coaxial-flowing gas so this is coaxial flowing plasma gas okay so maintains it in a plasma state. So here this workpiece is electrically conducting. So these are the 2 modes arc mode, one is the non-transferred and second one is the transferred arc mode.

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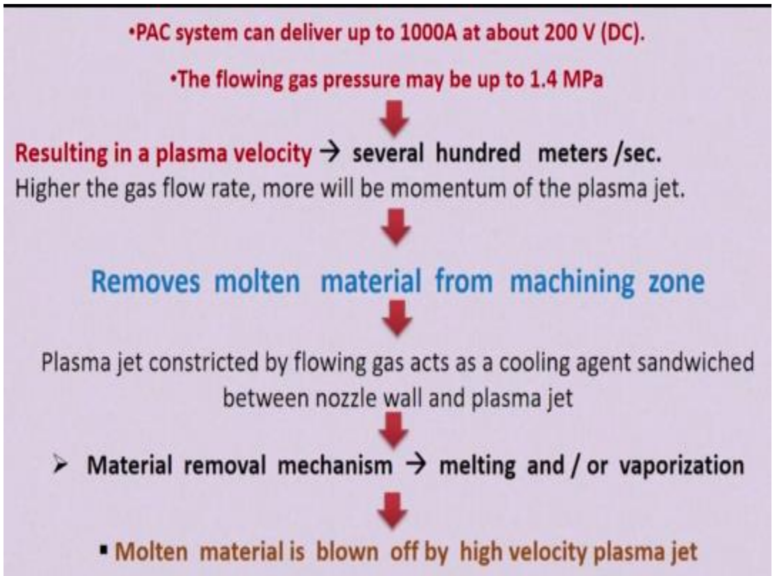

So plasma arc system can deliver up to 1000 ampere at about 200 volt DC. So this flowing gas pressure is it should be more than 1.4 MPa. So because of this high pressure of this plasma gas this plasma velocity is very high. So velocity of plasma gas is very high. So as this plasma gas velocity is very high with a high velocity jet of this plasma gas can remove the molten material from the workpiece surface. So this plasma gas velocity it maybe several 100 meters per second. So higher the gas flow rate, more will be the momentum of the plasma jet. So with a very high velocity of plasma jet so with a very high momentum of the plasma jet will be there.

So material is removed by melting and vaporization because this huge amount of heat generation and temperature rises around 33000 degree centigrade, so this amount of heat can melt and vaporize the material where this plasma jet actually touches on the workpiece surface. So removes material by melting and vaporization and because of this high velocity plasma jet whatever this molten material is there or vaporized material is there it is blown off from the machining zone using by the high velocity plasma jet.

So plasma jet constricted so this plasma jet is constricted by the flowing gas sometimes or shielding gas, so it acts as a cooling agent. So it acts as a cooling agent. So it is sandwiched between the nozzle and the plasma jet, nozzle wall and the plasma jet. So this flowing gas acts as a cooling agent and sandwiched between the nozzle wall and the plasma jet. So this material removal mechanism from the workpiece surface obviously it is melting and vaporization. So molten material is blown off from the high velocity plasma jet because of this high pressurized plasma jet is used, it generates huge amount of velocity of the plasma jet, whatever this molten or vaporized material is there it is blown off from the machining zone.

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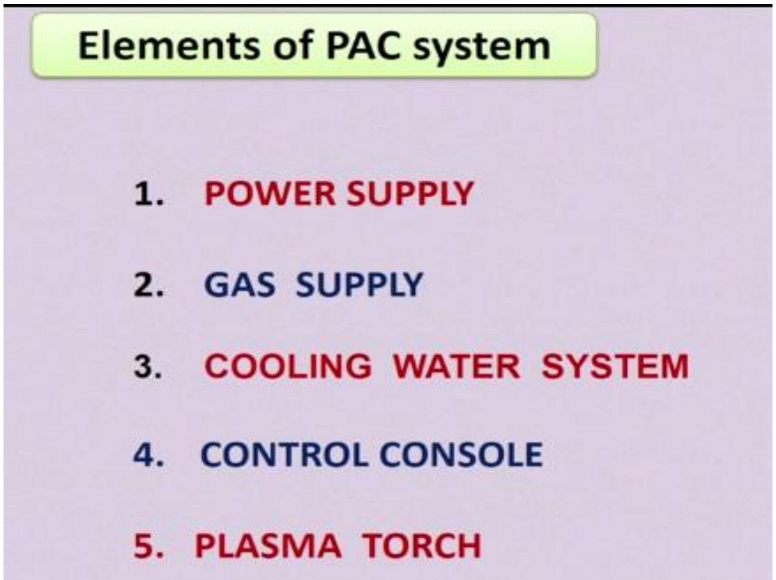

So these are the different elements of the plasma arc machining system. So first one is the power supply. Second one is the gas supply, plasma gas supply system. Then cooling water system. So you have to cool down this nozzle as well as the plasma jet you have to cool down and then control console. So this plasma jet can be controlled by using a CNC machining system or this working table may be controlled by using a CNC machining system, CNC system so that any complicated contour can be cut from the workpiece material and also the fifth one is the fifth one of the plasma arc system, plasma arc cutting system is the plasma torch.

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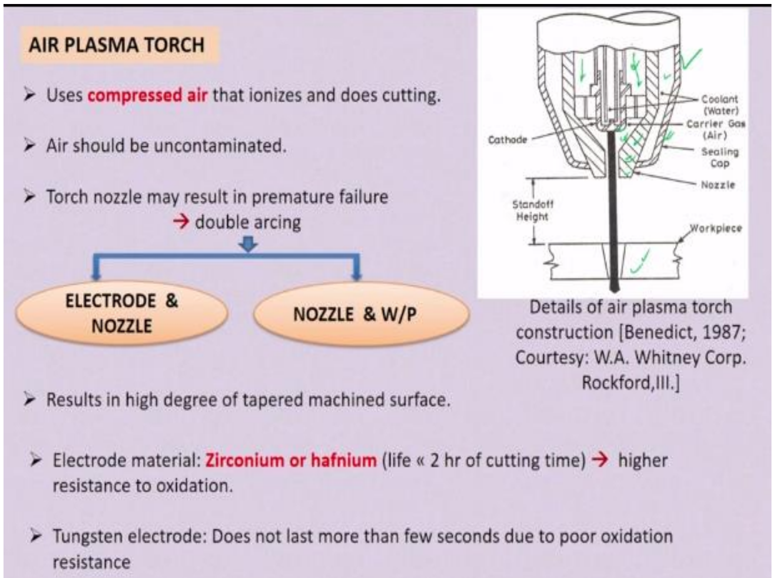

So there are different kinds of plasma torches are available in the market. So first one is the air plasma torch. So you can see at the right hand side here this is the schematic diagram of the air plasma torch. So this is the carrier gas, so this carrier gas is coming, so this carrier gas or plasma gas is here, it is the compressed air. So here compressed air is used. So this compressed air actually it is filtered compressed air. So this air should be uncontaminated. If this contaminated air is coming or some moisture is there so because of this huge temperature so it will damage the nozzle. So that is why this air should be filtered and uncontaminated compressed air is used as the plasma gas in this kind of air plasma torch.

So it uses compressed air that ionizes and does the cutting action. So this is the nozzle here. So outside there is a sealing cap is there, just outside this nozzle there is a sealing cap and in between this nozzle and sealing cap there is a coolant water is there. So coolant water is flowing so that whatever this heat is generated in the nozzle that heat can be dissipated into that coolant water. Otherwise it will if it is this nozzle is heated up for a longer time with a very high temperature then its life will be reduced.

So if we use this coolant to remove this heat from the nozzle so its life can be enhanced. So through this gap surrounding this nozzle this compressed air is coming. It is passing through this nozzle. So here uses compressed air at the for ionization and this compressed air is ionized and does the cutting operation. So air should be uncontaminated, this compressed air should be uncontaminated. Torch nozzle may result in the premature failure.

So there is the double arcing is there. So arcing maybe between this electrode and the nozzle and in between this nozzle and the workpiece. So there may be double arcing is there. So arcing may happen in between this electrode and this nozzle and in between this nozzle and this electrode. So here torch nozzle may result in the premature failures because of this double arcing. So double arcing between the electrode and nozzle and nozzle and the workpiece. So this kind of air plasma torch results in high degree of tapered machined surface.

So machined surface or cut surface on the workpiece it shows high degree of taper. So this electrode material used for this kind of nozzle air plasma nozzle is hafnium or zirconium. So this hafnium and zirconium it has a 2 hours of life. So these kind of materials is used because it has a high resistance to the oxidation.

So that is why this kind of hafnium and zirconium is used. Tungsten electrodes are not used because tungsten it does not last more than few seconds due to the poor oxidation resistance. So if we use tungsten electrode so it does not last for more than a few second because it has a very poor oxidation resistance so that is why tungsten is not used as a electrode material in case of air plasma torch. So only this hafnium and zirconium is used which has a 2 hours of life and it has a higher oxidation resistance also.

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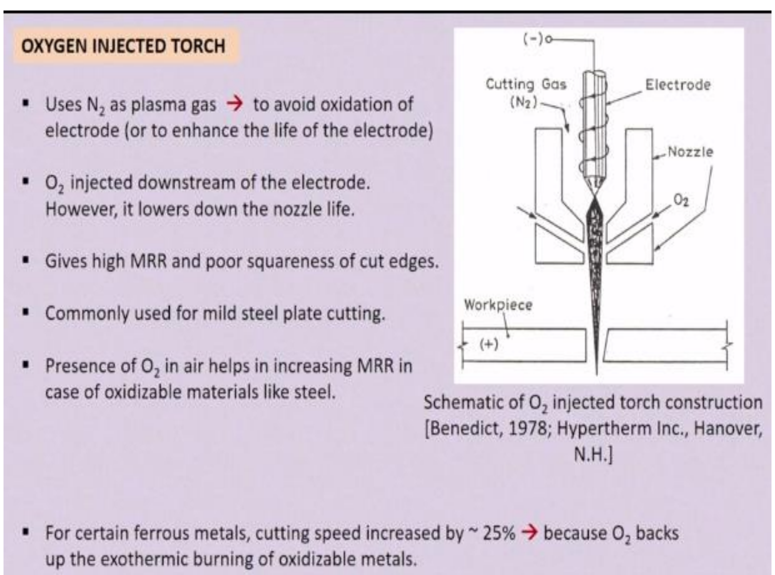

Now second one is the oxygen injected torch. So this one is the oxygen injected torch. Here is the nozzle. You can see this is the nozzle here and this is the part of this nozzle. So this is and through this nozzle you can see oxygen is injected. So oxygen is used as a shielding gas. So in this case oxygen gas is used in the as a shielding gas and nitrogen is used as the plasma gas. So here you can see this nitrogen is used as the plasma gas so this nitrogen or cutting gas or plasma gas nitrogen is coming surrounding this electrode and it is passing through the nozzle. So this is transferred type, transfer mode type of nozzle.

So you can see this is negative terminal is connected to this electrode and positve terminal is connected to the workpiece. So it is a transfer mode of electrode, the transfer mode of torch, plasma arc cutting torch okay. So oxygen is actually flown through this nozzle at the side of the nozzle you can see here. So it acts as a oxidising agent. So oxygen for some ferrous materials, it increases the exothermal reaction, so it increases the efficiency for a ferrous material.

So uses so oxygen injected torch uses nitrogen as the plasma gas and to avoid the oxidation of this electrode to enhance the life of the electrode. So nitrogen is used because in air plasma torch oxygen maybe there so because of this oxygen into the compressed air so it oxidises the electrode, but in case of oxygen injected torch nitrogen is used as the plasma gas so it reduces the oxidation of the electtode.

So it avoids the oxidation of the electrode and hence life of the electrode is increased. So oxygen is injected at the downstream of the electrode here you can see alrady I told. As oxygen is injected through the nozzle here, here oxygen actually it oxides the electrode and it lowers down the nozzle life but it has a certain application why this oxygen is used because due to the application flowing of this oxygen material removal rate becomes very high for a ferromagnetic material. So it gives poor squareness of the cut edges but it gives high material removal rate. So it is commonly used for cutting mild steel plate which is a ferromagnetic material, which is a ferrous material.

So it is used for the mild steel which is a ferrous material. So presence of oxygen in air helps in incorporating material removal rate in case of oxidisable materials like steel. So it helps in increasing material removal rate in case of oxidisable materials like in steel. So for certain ferrous metal cutting speed is increased by 25%. So because oxygen backs up the exothermic burning of this oxidisable metals. So oxygen helps in exothermic burning of this oxidisable materials.

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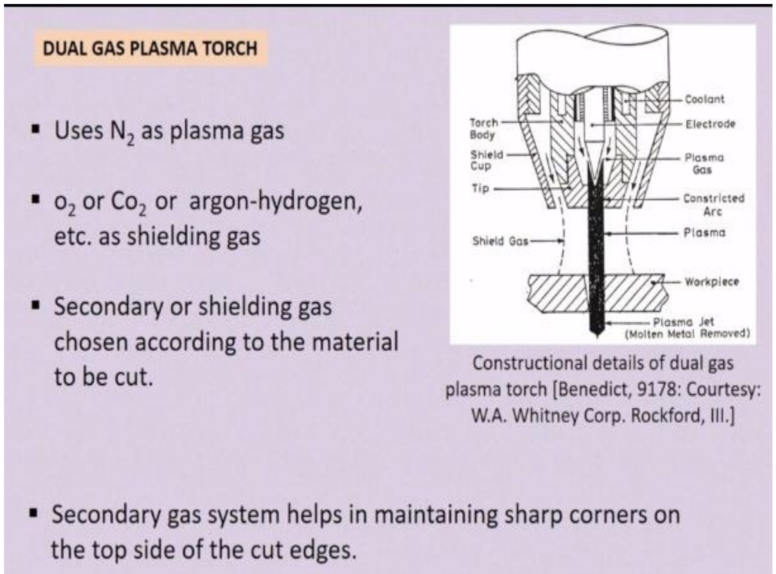

So now dual gas plasma torch, third one is the dual gas, gas plasma torch. Here this plasma gas you can see nitrogen is used as the plasma gas and outside you can see here this shielding gas also used surrounding this nozzle shielding gas is used to reduce the temperature of the nozzle. It helps in reducing the temperature of the nozzle. Also it helps in guiding this plasma so that top surface, top cut surface on the workpiece become perpendicular, top edge cut on the workpiece surface becomes perpendicular. So this dual gas plasma here you can see this plasma gas and here outside there is a shielding gas is used.

So this is the coolant here in this into the nozzle this coolant is used to reduce the temperature again. So this is the electrode here. So this is the nozzle here and this is the workpiece, so this is the workpiece and this is the shielding gas here outside this plasma. So this is the plasma here which is generated. So this dual gas plasma torch it uses nitrogen as the plasma gas and oxygen or carbon dioxide or argon, hydrogen are used as the shielding gas.

So oxygen, carbon dioxide, argon or hydrogen any one of these can be used as the shielding gas based on materials you are cutting. Secondary or shielding gas is chosen according to the material to be cut. So if you are cutting some ferrous material you can use oxygen as the shielding gas or in other cases you can use carbon dioxide or argon, hydrogen, etc., as the shielding gas. So this secondary gas system helps in maintaining the sharp corner of this on the top side of the cut edges.

So here you can see because of the shielding gas this top edge cut on the workpiece surface it you can see this sharp edged corner. So this perpendicular, this vertical cut maybe there on the top surface of the workpiece. So this taperness is reduced in case of this dual plasma dual gas plasma torch and also it guides the plasma channel, it guides the plasma gas this shielding gas also guides the plasma gas so that it can be concentrated into a smaller area.

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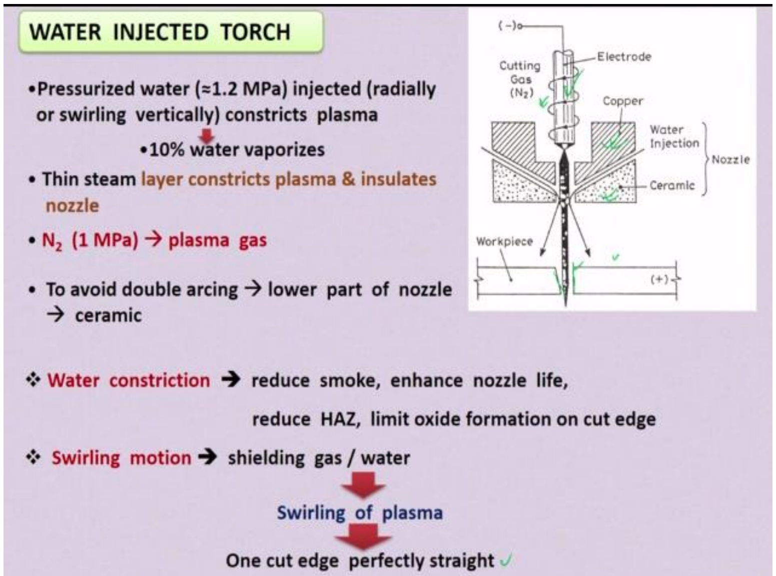

Now fourth one is the water injected torch. So here you can see this is the electrode here and plasma gas as usual it is flown surrounding this electrode and this is the copper nozzle. You can see this is the copper nozzle here and here ceramic this nozzle at the bottom side of this nozzle ceramic materials is used to reduce the double arcing. So in first one air plasma torch we have seen that there are double arcing is there.

So double arcing in between the arcing between the electrode and the nozzle and arcing between the nozzle and the workpiece to reduce the double arcing here at the bottom side of this nozzle there is a ceramic material is used. So it is a non-conducting electrically non-conducting material. So there will not be any double arcing in case of this water injected torch. So water is injected in between this nozzle and this ceramic material.

So here it is injected here from the sidewall it is coming water is coming here. So as this water is coming so immediately when it touches to the plasma gas immediately small portion, 10% in volume of this water actually vaporizes. So because of this vaporizing of this water it actually make a shielding environment surrounding this plasma, surrounding this plasma gas it makes a shielding environment. Also it insulates the nozzle.

So pressurized water around 1.2 MPa is injected radially or swirling vertically or it may be swirling also this water also maybe swirled, it may be given swirling machine also. So it constricts the plasma. So its work is to constrict the plasma, to seal the plasma and 10% water vaporizes. The stream layer constricts the plasma and insulates the nozzle. So it constricts the plasma, this vaporized water, it constricts the plasma and it insulates the nozzle.

So nitrogen with 1 MPa is used. So because of this high pressure plasma gas as a nitrogen it creates a huge velocity of this plasma. So to avoid this double arcing lower part of the nozzle is made of non-conducting ceramic material. So water constriction so because of this constriction of this water it helps to reduce the smoke because this high velocity, high temperature, around 33000 degree centigrade this plasma when it is touching to the workpiece surface, it generates huge amount of smoke. So to reduce this smoke and noise this water constriction helps to reduce the smoke and noise and it enhance the nozzle life also and reduces the heat affected zone into the workpiece surface. So limit the oxide formation on cut edge.

So you can see this because this high temperature is used for cutting the material, so after cutting immediately this molten material it is blown off but this workpiece material actually it comes into a very high temperature jet plasma jet so it is also heated up so at this high temperature because of this surrounding oxygen environment is there so this material actually immediately it oxidize in case of plasma arc cutting. But when you are using this water injection through the side wall so it limits the oxide formation on the cut edge. It reduce the heat affected zone and it increases the nozzle life and it reduces the smoke.

So sometimes there are swirling machine is given to the water, so because of this swirling machine you can see one side of the cut edge is perfectly vertical and another side it is inclined, it is tapered. So one side of the cut edge becomes perfectly vertical if we give a swirling machine. So because of this swirling machine it generates a higher shielding gas or water environment there and swirling of plasma one cut edge is perfectly straight. So here one cut edge it is perfectly straight because of this swirling motion of the water.

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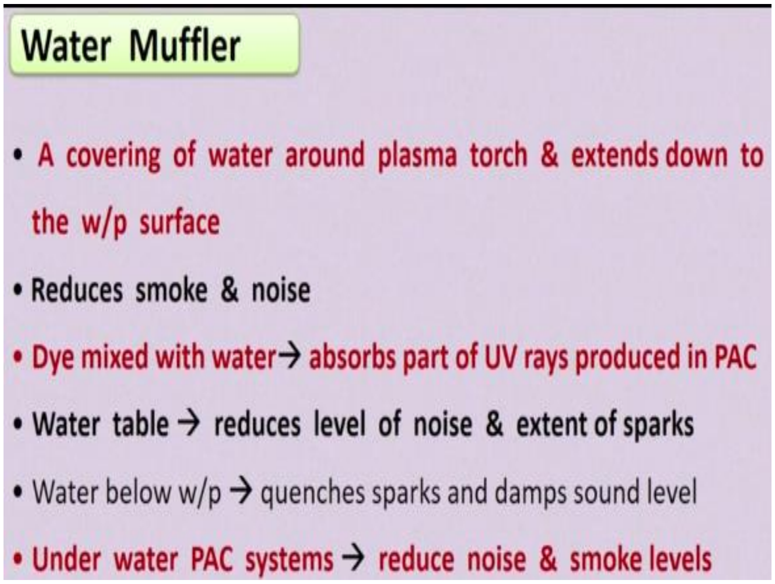

So water muffler. Water muffler is that a covering of water around the plasma torch and it extends to the workpiece surface. So in case of water injected torch so a water muffler is generated. A water muffler is nothing but a covering of water around this plasma torch and it extends to the workpiece surface up to the it extends up to the workpiece surface.

So as this water muffler it extends up to the workpiece surface it reduces the smoke and reduces the noise. So reduces the noise generated due to the high velocity plasma arc into the workpiece surface. So it reduces smoke and it reduces noise. Sometimes dye is actually mixed with the water so that this dye in the water it absorbs the ultraviolet ray generated during plasma arc machining operation.

So it absorbs the part of the ultraviolet rays produced during plasma arc cutting operation and sometimes water table is used to reduce the velocity of this plasma jet, also to reduce the noise generated by the high velocity plasma jet and also it reduces the extent of sparks. Water below the workpiece quenches the spark and damps the sound level. So it quenches the spark, water below the workpiece, and damps the sound level also. Sometimes people are using underwater plasma arc cutting system. So it is under development. So it reduces the noise and smoke levels which is huge in case of normal plasma arc cutting system.

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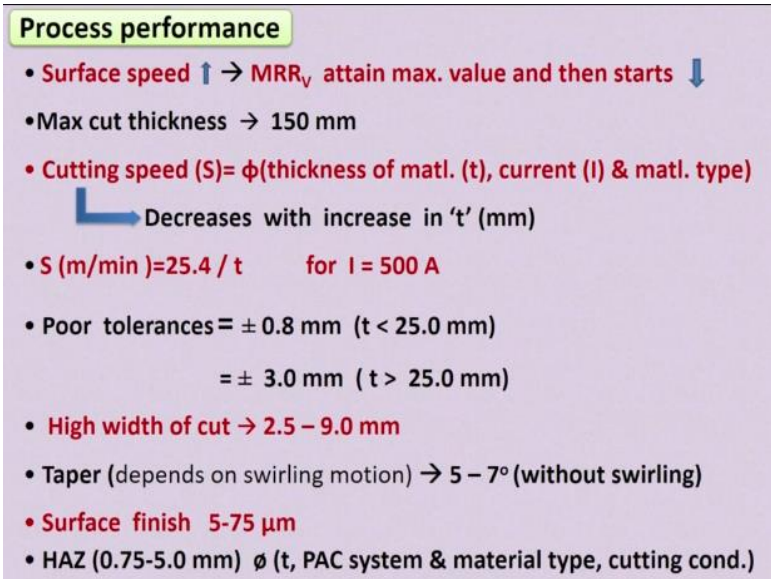

So now process performance we have to discuss, process performance of plasma arc machining system. So when this surface speed, speed of the workpiece is very high in that case material removal rate reaches to a maximum level. Now if we increase the cutting speed of the workpiece this material removal rate after reaching to a maximum level then again it is reduces, start decreasing okay. So surface speed of the workpiece if we increase material removal rate increase to a maximum level and beyond that surface speed again this material removal rate reduces.

So maximum thickness of the material that can be cut on the workpiece it is 150 mm that is the maximum thickness of the workpiece material can be cut by plasma arc machining process. So this cutting speed actually depends on the surface speed, speed of this workpiece material and then material property, property of this material and also thickness of the material, thickness of the workpiece you are cutting.

So this cutting speed it depends on the thickness of the workpiece material you are cutting, workpiece material property, and surface speed of the workpiece material. So it is a function of this t, also it is a function of current also, current I. So this cutting speed decreases with the increase in the thickness. So if you increase the thickness of the workpiece material your surface speed will reduce, cutting speed or sorry your cutting speed will reduce if you increase the thickness of the material, workpiece material.

So if you write this one in terms of equations this surface speed of this or cutting speed of this material, workpiece material it is in meter per minute is equal to 25.4 by t for current equal to 500 A, power supply, current from the power supply equal to 500 A. So S equal to 25 by t. So when thickness of this workpiece material increases surface speed or cutting speed reduces. So generally this tolerances generated by plasma arc machining system it is very poor. So tolerances when you are cutting workpiece material less than 25 mm.

So in that case it is comparatively better so in that case tolerance is around plus minus 0.8 mm. But when your thickness of the workpiece material is higher than 25 mm in that case you are you get very less tolerances, it is plus minus 3 mm. So from less than 1 mm it goes beyond plus minus 3 mm. So plasma arc cutting process generates very high width of cut, around 2.5 to 9 mm, this is the width of cut in case of plasma arc machining process.

So it is a very high width of cut. Taper so it depends on the whether you are doing the swirling motion or not. If you are giving a swirling motion of the surrounding gas, shielding gas or shielding water so in that case your taper can be reduced to a smaller value. So without swirling you will get 5 to 7 degree of taperness into the cut material.

So surface finish achieved on the machined surface it is very poor. It is 5 to 75 micron in case of plasma arc machining process and also high huge amount of heat affected zone is formed on the machined surface so this heat affected zone it may be around 0.75 mm to 5 mm, so this much of heat affected zone is formed in case of plasma arc machining process. So this heat affected zone is a function of thickness of the workpiece material, plasma arc system and material type, what kind of material you are cutting and cutting condition also. So it depends on the, heated region, it depends on the thickness, plasma arc system, and material type, and cutting condition.

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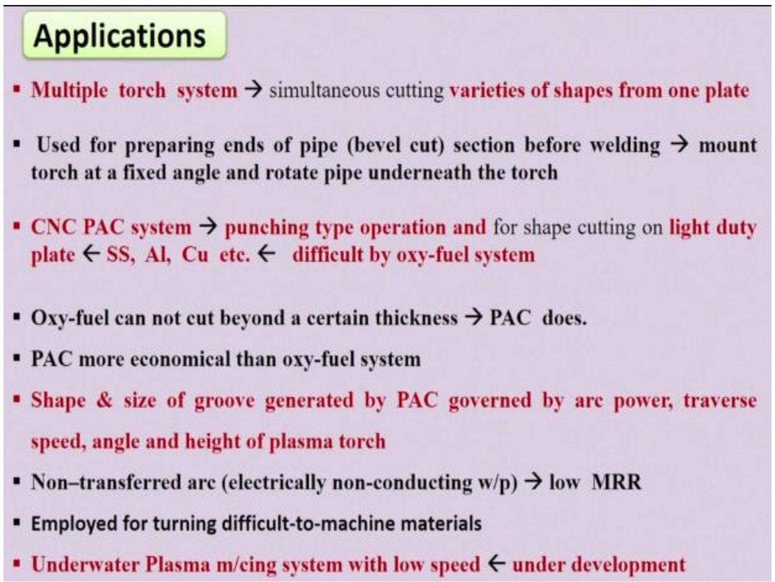

Now applications of this plasma arc machining system. So this mostly this plasma arc machining system is used for cutting purpose, cuting for cutting of high thickness material which is not possible by normal oxy-fuel cutting process. So generally this high thcikness materials are cut by this oxy-fuel cutting process but when it is not possible by oxy-fuel method then we go for this plasma arc cutting operation. So applications are multiple torch system which is used for simultaneous cutting of variety of shape from one plate.

So multiple torch you can use, instead of one torch you can use multiple torch for cutting varieties of shapes from the from one plate. So it is used for preparing ends of a pipe bevel cut at a certain angle. So for preparing the ends of the pipe so this for generating this bevel cut section before welding. So you need to do the preparation of the edge, edge preparation is required before welding so this edge preparation is done by the plasma arc cutting operation. So in that case torch is actually mounted at a certain fixed angle and pipe is actually rotated underneath the torch so that this or this pipe is actually it is cut at a certain angle.

So like torch is actually it is kept at a certain angle and at the at the bottom of this torch this pipe is actually rotated so that pipe edge can be cut at a certain angle. So when it is this workpiece is connected to a CNC system, so it is called CNC operated plasma arc cutting system. So this kind of CNC operated system is used for punching type operation and for shape cutting of light duty plates like stainless steel, aluminium, copper, etc., which is very difficult for cutting by oxy-fuel system. So oxy-fuel system cannot cut beyond a certain thickness so in that case this plasma arc cutting system can be used.

So plasma arc cutting system can cut very high thickness so that is why it is more economical than your normal oxy-fuel cutting system. So this plasma arc system is more economical. So this shape and size of the group generated by plasma arc cutting system is governed by the arc power, traverse speed, angle, and height of the plasma torch, height means this stand of distance of the plasma torch. So this non-transferred arc electrically non-conducting workpiece can be used for electrically non-conductive workpiece also.

It has a low material removal rate, this transferred arc has a high material removal rate. Also it has a high electrothermal efficiency. So this kind of plasma arc system is employed for turning difficult to machine materials. So underwater plasma machining system with low speed is under development. So these are the applications of plasma arc machining system. So with this I am ending this plasma arc machining system.