Manufacturing Process - I
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Module - 3
Lecture - 1
Introduction

Welcome students. This is the first lecture on the instruction of the welding. This is series of lectures on the welding.

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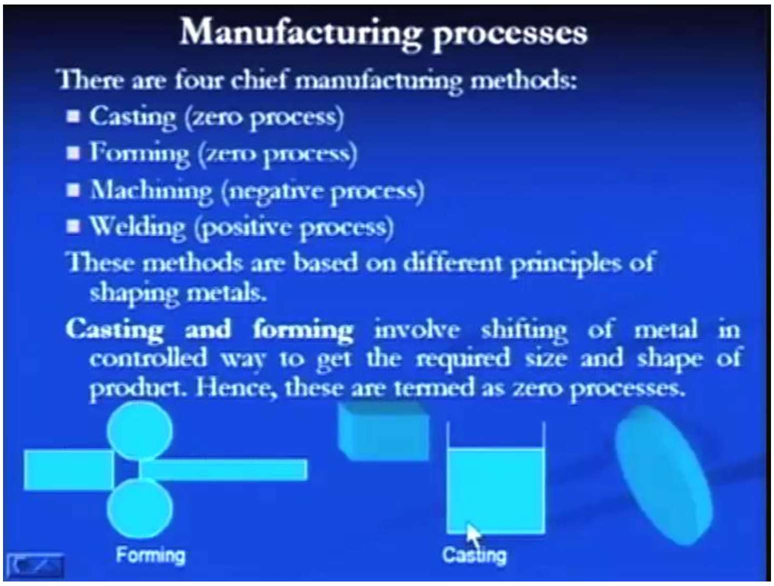

So, we will first talk about the manufacturing processes, which are basically used for shaping the materials as per size and the shape required for a making the engineering components. Therefore, manufacturing methods commonly used for shaping the engineering components, and these four manufacturing methods are: casting, which comes in zero process category; forming, which comes under the zero process category again; then machining - negative process; and then the welding - positive process. This classification is based on the way by which material is processed to get the desired shape.

These methods are based on the different principles of shaping metals like casting and forming involve shifting of the metals to get the desired size and shape of the product. And hence, these are termed as zero processes. In these two processes, no addition or deletion of the material takes place; mainly shifting of the material from one region to another is used to get the desired size and shape.

The first process, say here, is the forming in which thick - greater thickness - strip is reduced to the smaller thickness; like this one when it is passed through the rollers. So, in forming, the system does a rolling process, basically used to reduce the thickness and increase the length. The volume of a material largely is same and only shifting of the material form one region to another region takes places.

The casting is another process where the raw material is brought to the molten state in the furnace, and then, that molten metal is placed into the mold to get the desired shape, like this disk. So, theoretically there is no loss in both these processes. Only the shifting of the material from one region to another region is used to get the desired size and shape.

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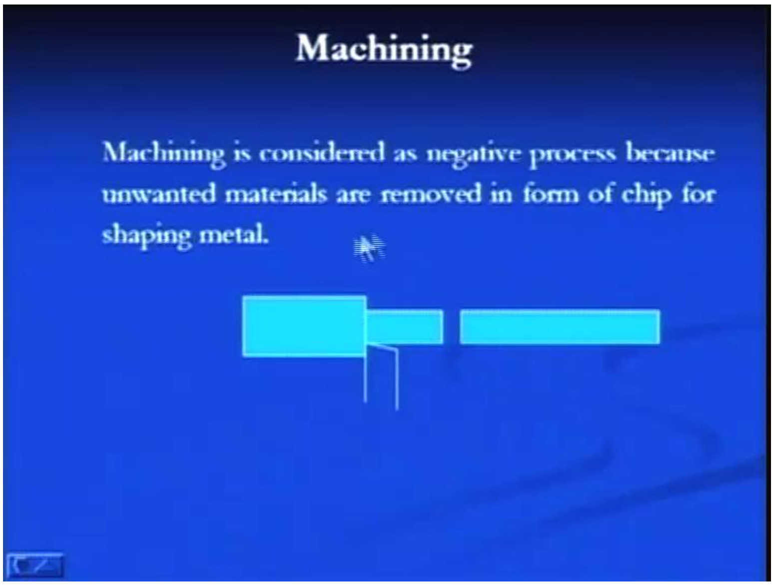

Machining is another fabrication technique in which… this is considered as a negative process, because unwanted material from the raw material or from the bulk material is removed in form of small chips for getting the desired shape of the metals.

Here, the material - say this is tool and this is the material being turned - and material is removed in form of chips, to get the final shape of this type. Unwanted extra material has been removed in this case. That is why these processes - the processes in machining, machining processes - are considered as negative processes.

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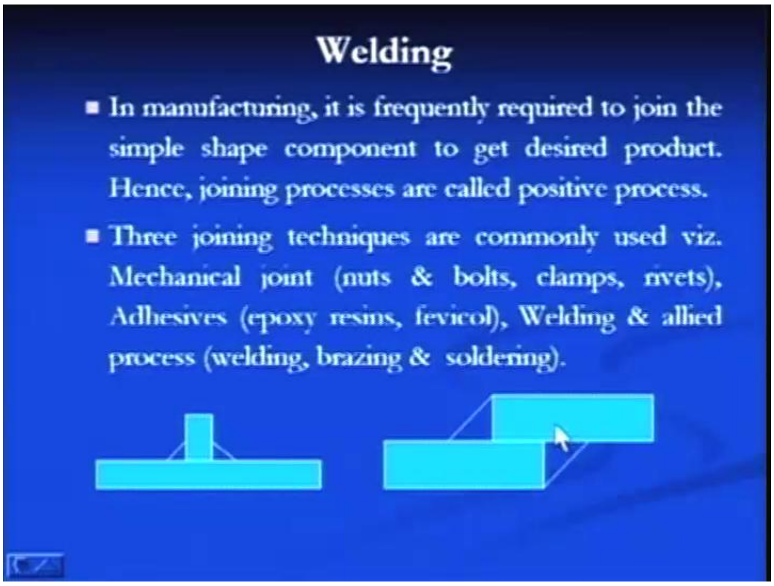

On the other hand, welding processes in which addition of the material is frequently used to get the desired size and shape. These processes in manufacturing are frequently used to join the simple shape components to get the desired product. Hence, these joining processes are called positive processes.

Three joining techniques are commonly used in engineering applications such as the mechanical joints where nut, bolts, clamps, and rivets, are used; adhesives in which epoxy resins and fevicol is used; and welding and allied processes, which includes the welding, brazing, and soldering. Welding based processes here, the simple shaped components are joined using the fillet belts - like this; here T kind of the joint is formed; and here fillet belts are used where two overlapping plates are joined; in technical terms, this is termed as a lap joint.

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The selection of the joint depends on the various factors; means before going for selection of particular joint, some of the factors should be considered first. This includes the type of the joint, which is required for a given engineering application, whether the joint is required for the temporarily - joint is required temporarily - or it is required in permanent way. So, if the permanent joints are required, then welding based processes are selected; and if a temporary joint is required, then the nut and bolts - kind of the joints - joining techniques are used.

The metal to be joined includes like steel, cast iron, aluminum, dissimilar metals, or any other combination. Some of the metals are easy to weld, but there is another category, which impose significant difficulty in joining by welding.

So, if the dissimilar combinations are particularly to be joined - like aluminum with steel, or aluminum with cast iron, or copper with aluminum, then welding - simple welding - processes are not found suitable; in that case mechanical or other joining - mechanical joints or adhesive joints - can be used. And a lot the work is going on in the area of the dissimilar metal joining by the fusion welding based processes.

The selection of the joint should also…in the selection of the joint it is required to consider the temperature conditions, the corrosion environment, the nature of the load, and the reliability required for a given surface before considering the type of the joint.

Here the requirement of service like temperature - some of the joints behaves in very undesired manner, like very low toughness is noticed in the welded joints and they perform poorly also in the corrosive environment. So, the selection of the type of the joint, whether it will be the welded joint, brazed joint, soldered joint, or mechanical joint, adhesive joint - all that will depend on the service conditions under which the joints are to be used.

Like the if the load is light, soldered joints can also work at low temperature or room temperature conditions, but if the load is severe - very high loading conditions are there at high temperature - then brazing and soldering will not be effective, and one should go for some welded joints rather than brazed or soldered joints. In the same way, if the environment is chemical and corrosive environment is there, then adhesive joints may also not be suitable.

In the last - it is also last, but not least - it is also important to see the economical aspects because the purpose of engineering in any form is to complete the activities with the minimum use of resources. So, such a joint, which can perform the desired function and can be produced at low cost, should be selected. So, that is what is the role of the economy - the joint which can perform the desired function and can be produced economically should be selected.

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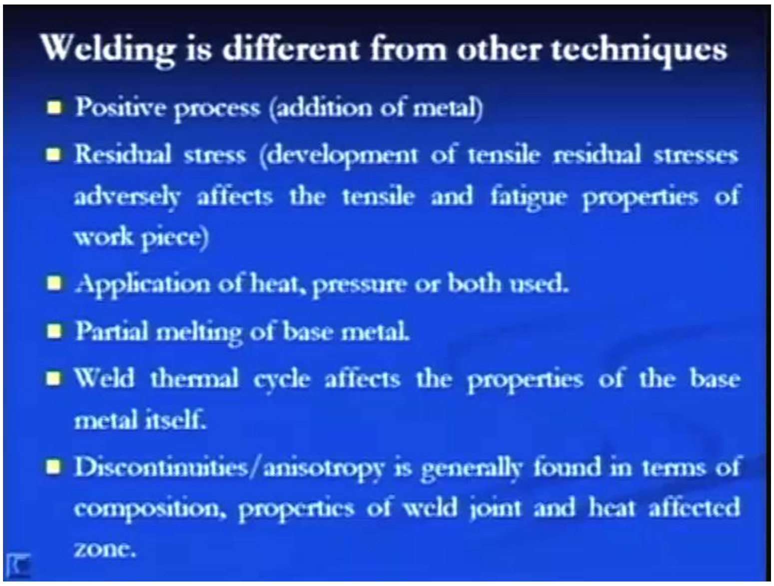

Welding is different from other manufacturing techniques in number of ways. Like the welding is considered as a positive processes, because addition of the metals is used to get the desired size and shape. The very undesirable aspect of the welding is the development of the residual stresses in weld metal and heat affected zone. Many times in the weld metal and in the heat-affected zone, tensile, residual stresses are developed, which adversely affect the tensile strength of the weldment.

If, somehow, the compressive residual stresses are developed in the weldment, then those help in improving the fatigue resistance of the of the metal; otherwise that the presence of the tensile residual stresses adversely affects the tensile and fatigue properties of the work piece. Residual stresses are those stresses which are present in the metal whether it is (( )) or heat affected zone without any external load. These are developed because of locked-in strain in the heat-affected zone, particularly in the welded joints.

In the welding we use the heat pressure either individually or both. There we have different categories of the welding processes in which only heat is used; and there is another category of the welding processes in which only pressure is used. Some the welding processes involves the use of both pressure and heat.

The partial melting of the base metal is the very special nature related to the welding manufacturing techniques, while in other fabrication techniques like machining or forming no melting take places, while in casting, complete melting of the base metal is used to get the desired size and shape.

Weld thermal cycle, which is encountered by the base metal during the welding is known to affect the base metal properties; particularly the region which is affected due to the weld thermal cycle is known as the heat affected zone and that many times leads to the softening or hardening of the heat affected zone. So that is why efforts are always made to reduce the effect of weld thermal cycle.

It is common to see that the discontinuities are found in the welded joints and the joint also shows the anisotropy and isotropy in terms of the composition properties of the weld joint and the heat-affected zone. The variation in the mechanical properties and the micro structural characteristics in the weld metal and heat affected zone, leads to the poor reliability of the heat affected joint.

There are few other points related to the dissimilarities in the welding compared to the other fabrication processes like poor reliability of the joint compared to the other manufacturing techniques.

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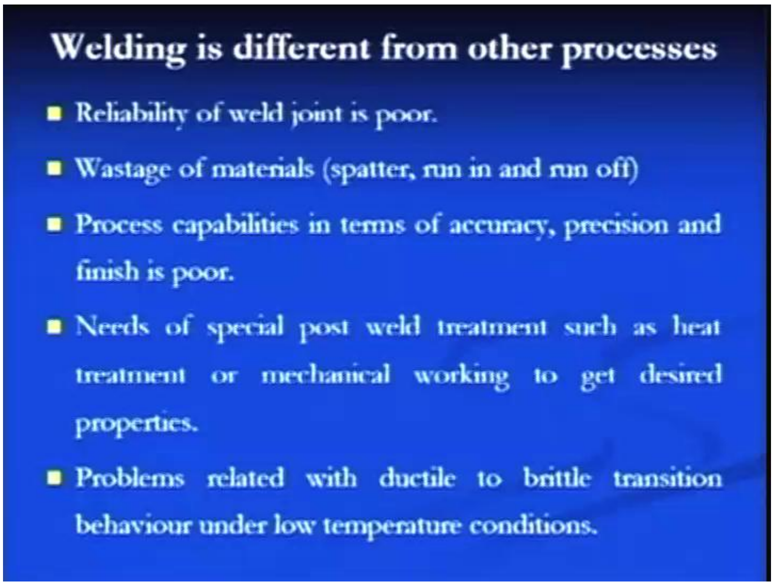

The components produced by the welding used are known to have poor reliability compared to those produced by the forming or the casting processes. Wastage of the material is also there in form of spatter, in run in portion, and run off portion, which this run in and run off portion needs to be removed before obtaining the final component for engineering application. The process capabilities - the capability - of the welding process is somewhat poor in terms of the accuracy, precision, and the surface, it is the surface finish that we get; many times it is required to go for post machining operations to get the desired size and shape accurately.

The need of the post weld treatment, such as the heat treatment and mechanical working is required to get the desired properties. The mechanical properties such as hotness, good yield, strength, and hotness are frequently obtained by the post weld treatment operations like normalizing - which helps to refine the grain structure - at the same time residual stresses are also relieved by the heat treatment operations like annealing or stress relieving operations.

If the material is work hardened mechanically - by mechanical working techniques - like rolling that helps to obtain uniformity in the properties of the heat-affected zone and in the weld metal. The problems related to the welding also cause the ductile to brittle transition behavior of some of the metals like the mild steel weld joints which shows significant ductility at room temperature, becomes brittle at a low temperature, say, about minus 10 to minus 20 degree centigrade temperature conditions. So, the weldability of the mild steel for room temperature application is considered good, while at for the low temperature applications below minus 10 or minus 20 degree centigrade, the weldability of the steel is considered poor.

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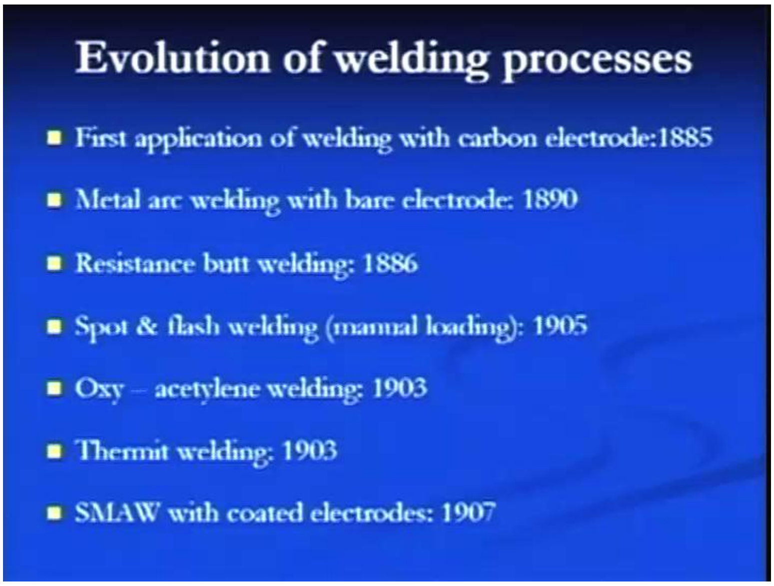
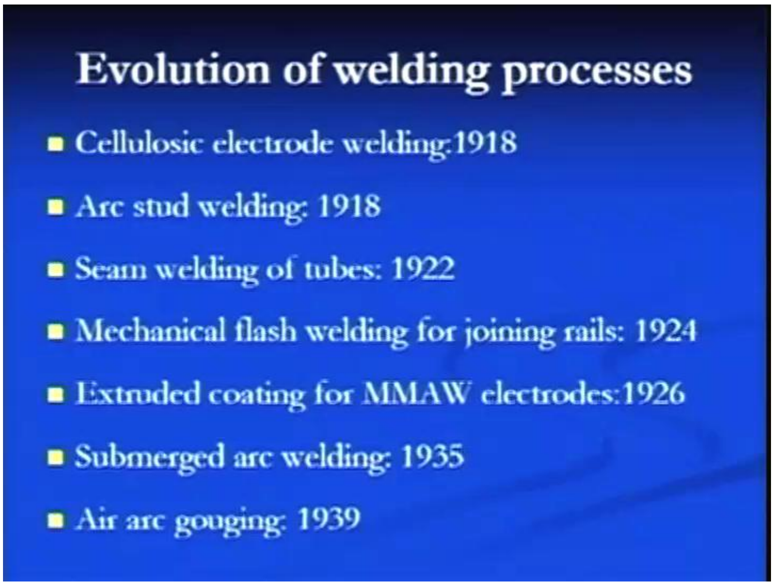


Now, we will see that how the different welding processes were developed right from the beginning. The first application of the welding with carbon electrodes is started in 1885; and then, metal arc welding with bare electrode was carried out in 1890. Resistance welding process was developed in 1886. Spot and flash welding processes, which were controlled manually, were developed in 1905. Oxy-acetylene welding was developed in 1903. Thermit welding process, which is even used now, what is for welding of the rail joints was developed in 1903. SMAW arc welding with coated electrode, which is mostly used for the general applications, even nowadays, was developed in 1907.



Cellulosic electrode welding was electrodes for the welding applications were developed in 1918. Arc stud welding process was developed in 1918. Seam welding of the tubes process was developed in 1922. Mechanical flash welding for joining rails was developed in 1924. Extruded coatings for manual metal arc welding electrodes were developed in 1926. Submerged arc welding process was developed in 1935. Air arc gouging process was developed in 1939.

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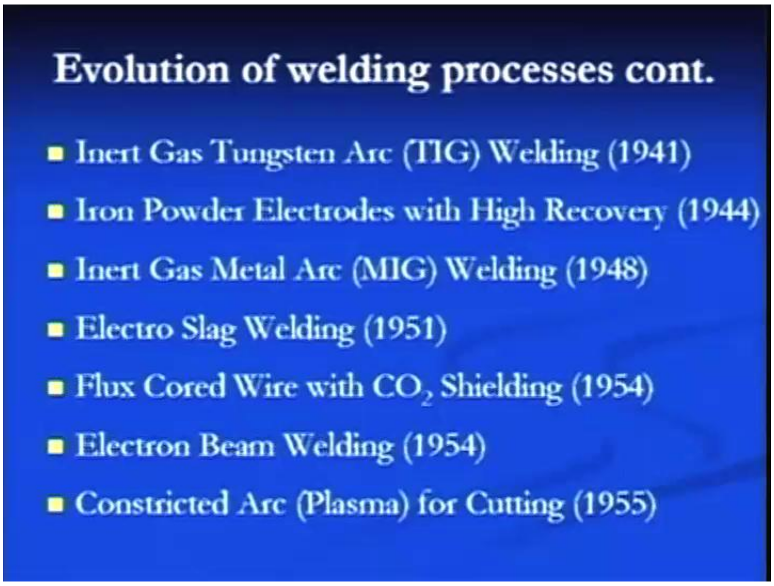

Inert gas tungsten arc welding, more commonly known as TIG, welding was developed in 1941. Iron powder electrodes with high recovery were developed in 1944. Inert gas metal arc welding process was developed in 1948; this process has great significance from the high deposition rate point of view for the commercial applications. Electro slag welding which is being used for very thick sheets welding - like in ship building industry - was developed in 1951. Flux cored wire with CO 2 shielding gas was developed in 1954. Electron beam welding was developed in 1954. And constricted arc plasma for cutting applications was developed in 1955.

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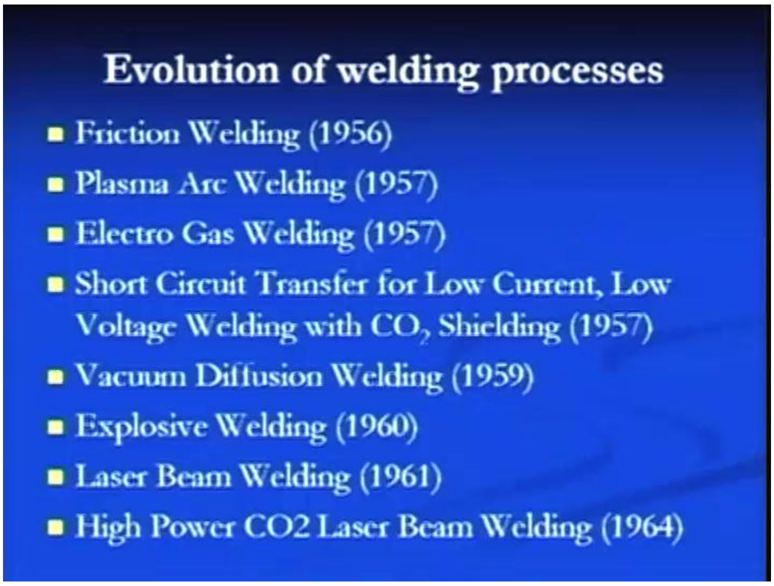

Friction welding process - lot of work is being done on this process even now a days - initially was developed in 1956. Plasma arc welding was developed in 1957. Electro gas welding was developed in 1957. Short circuit transfer for low current low voltage welding with CO 2 was developed in 1957. And vacuum diffusion welding process was developed in 1959. Explosive welding process, which is normally used for the difficult to weld metals or the dissimilar combinations, was developed in 1960. Laser beam welding process was developed in 1961. And high power CO 2 laser beam welding process was developed in 1964.

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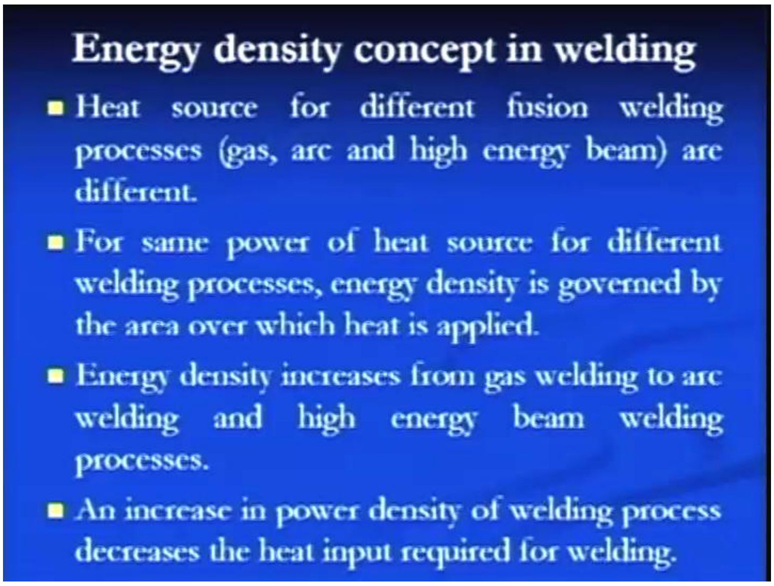

In the welding processes, normally, heat source is used for joining purpose, and the joints are produced normally by fusion of the base metal. And heat source for the different fusion welding processes are different like in gas welding, it is the gas flame which is used; in arc welding process the high energy beam like electron beam or lasers are used in the high energy beam based welding processes.

For same power of the heat source for different welding processes energy density is found different, because energy density is governed by the area over which heat is applied. The energy density increases from gas welding to the arc welding, and then further higher energy density is obtained in the high-energy beam welding processes. An increase in power density of the welding process decreases the heat input required for the welding. Energy density depends upon the area over which heat is being applied; smaller the area over which heat is applied, higher the energy density is obtained.

If the power density of welding process is high, then it needs lesser amount of the heat input for melting the base metals and producing a joint. And that is why it is said that an increase in power density of the welding process, decreases the heat input required for welding.

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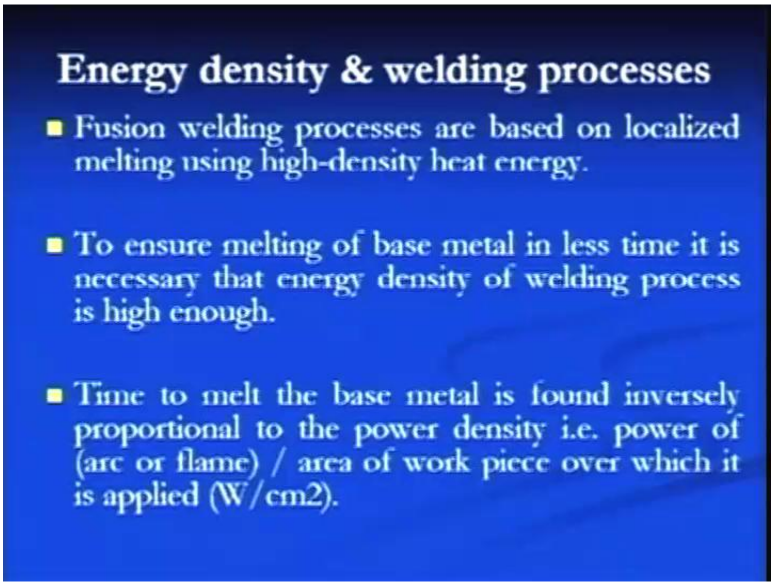

The fusion welding processes are based on the localized melting using the high energy high density heat energy, because high-energy high density heat energy is important, because the heat is applied in localized manner to the faying surfaces to get the partial molten condition of the metal to be joined. To ensure the melting of the base metal in less time, it is necessary that the energy density of the welding process is high enough. If the energy density is not high enough of welding process, then whatever heat is supplied that is transferred away from the faying surfaces and material is not brought to the molten state. The time to melt the base metal is found inversely propositional to the power density of the heat source being used; that is the power of the arc or flame divided by the area of the work piece over which heat is applied and it is normally expressed in terms of watt per centimeter square.

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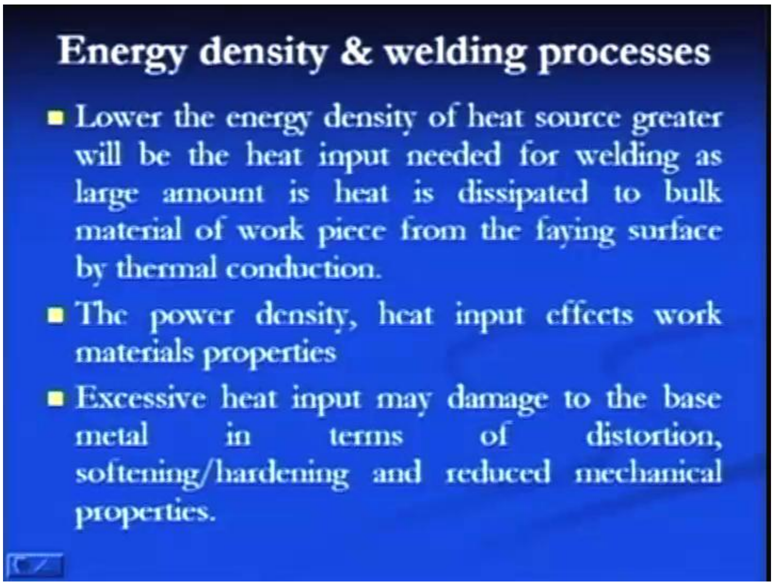

Lower the energy density of the heat source, greater will be the heat input required for the welding, as large amount of heat is dissipated to bulk of the work piece from the faying surface by thermal conduction. So, if the heat energy density is low, then lot of heat is to be supplied to bring the faying surfaces to the molten condition. And it takes longer time also to bring the faying surfaces in molten condition, because lot of heat is dissipated to the bulk material of the work piece.

The power density heat input affects the mechanical properties; both these characteristics - the power density at heat and heat input - affect work material properties particularly in the heat-affected zone. If the energy density is high, heat input will be low and effect on the work piece material will also be less; but if the power density is low, then heat input will be high, and there will be more effect on the work material properties of the well joints.

The excessive heat input may damage the base metal in terms of the distortion softening or the hardening and reduced mechanical properties. High heat input adversely affects the joint performance in general, and it has been observed that increase in heat input increases, the distortion related problems, more effect on the heat affected zone properties like either hardening or the softening is noticed and adversely affects the joint properties - weld metal properties itself.

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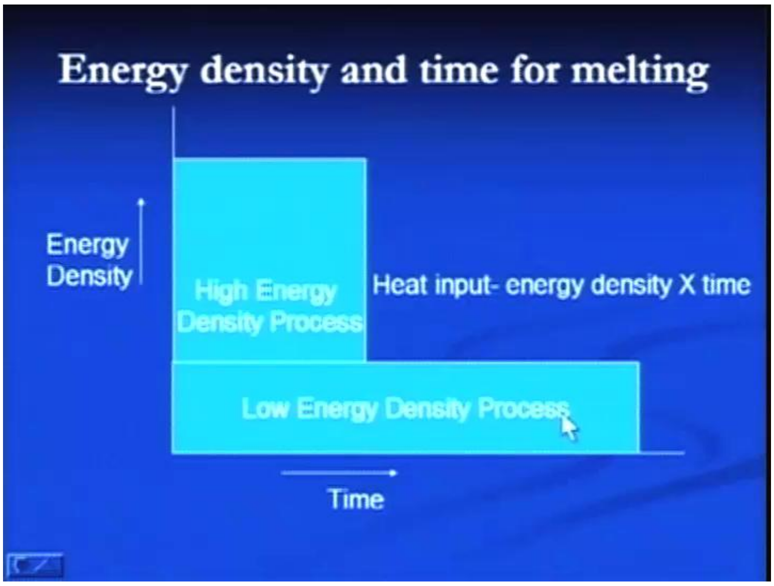

So, that effect you can see here. If the energy density is high - here in this diagram, it has been shown schematically - if the energy density is high for a given amount of heat it takes less time, while low energy density process takes longer time to provide the same amount of heat. The heat input, which is required for bringing the metal to the molten condition, it is determined by the base metal itself first; if the heat input has been obtained, then heat input required for melting the base metal is found equal to the energy density multiplied by the time. Higher the energy density, lower is the time required to melt the metal and to produce the joint; and lower the energy density, longer is the time required for bringing the metal to the molten condition to produce the joint.

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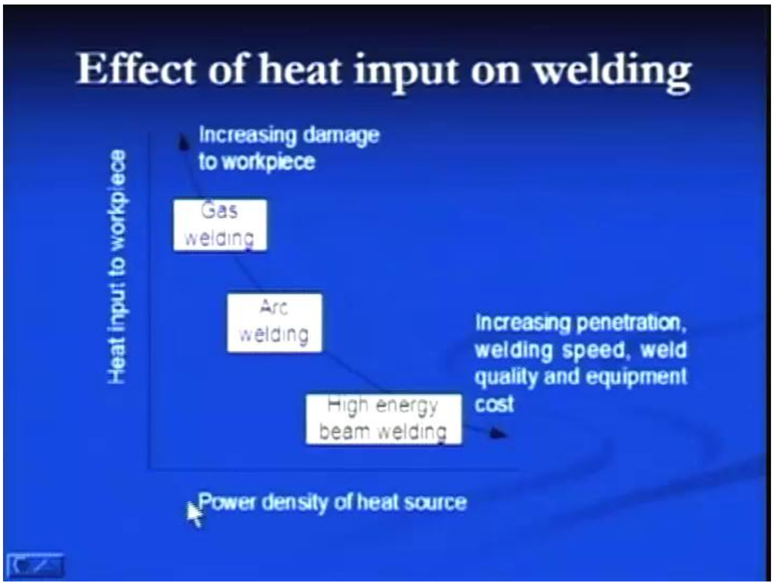

Effect of the heat input on the weldment performance can be seen from this diagram. Power density of the heat source on this abscissa and the ordinates, you can see the heat input to the work piece; lower the energy density, lower the power density, higher the heat input required for producing the weld joint. Low power density welding process - like cast welding - needs the higher heat input for producing the joint. Somewhat higher power density heat source, like arc welding process, the heat input required for producing the weld joint reduces. And for further higher energy density, for power density heat source, like in high energy beam welding, for example, laser beam or electron beam welding, the heat input required for welding of the metals further reduces.

So, you can see here, higher the power density of the heat source… the higher the power density of the heat source, lower the heat input required for producing the joint. Lower the power density, higher the heat input. The effect of the heat input can be seen if the heat input to the work piece increases, then it leads to the increased damage to the work piece in terms of the mechanical properties, distortion, residual stresses, etcetera.

On the other hand, if the power density is high, heat input will be reduced, and that in turn will give the advantages like increased penetration, higher welding speed, high weld quality, but the equipment cost is also high in this side. So, this way we can see the power density of the heat source significantly affects the performances of the welding process and the weld joint performance - both.

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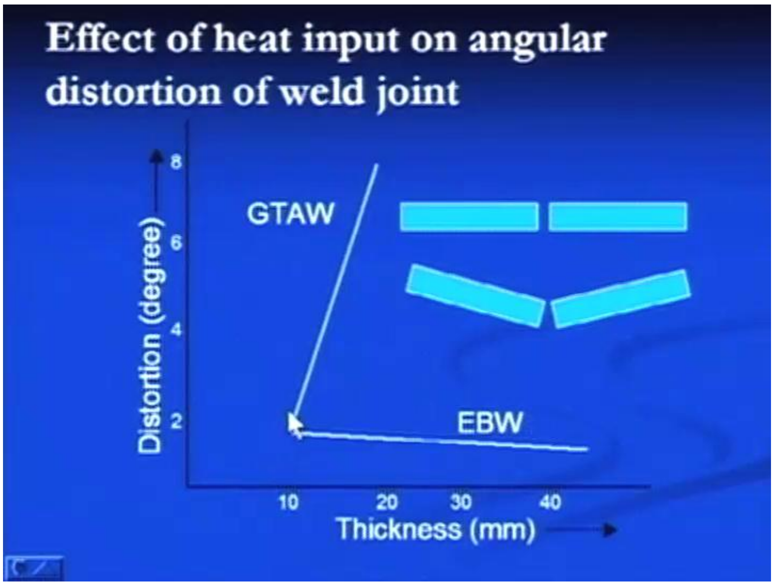

Just for example, we can see here, the effect of heat input on the angular distortion, with the increase in thickness of the plates welded by the low energy density welding process and high energy density welding process like electron beam. So, if we compare these two welding process - one of the low energy density welding process like gas, tungsten, arc welding, with high energy density welding process like electron beam welding.

The angular distortion, which is noticed, increases continuously with the increase in thickness of the plates in case of the GTA - gas tungsten arc welding; while in case of high energy density processes, there is no significant increase; largely it decreases with increase in thickness.

So, means if the higher thickness plates are to be welded, then electron beam welding process would be more suitable compared to the GTA welding process, as it leads to the distortion - angular distortion - and that angular distortion could be understood easily from this schematic diagram. Here it is required that after welding, both these parts will remain in line, and so, and here, the joint is produced, but sometimes what happens that if the due to the weld thermal cycle encountered by the base metals during the welding, angular distortion takes place, and because of that, the two plates bend about the axis of the… about the weld center line, but this angular distortion effect is less in case of high energy density welding process like electron beam welding and it is more in case of the gas tungsten arc welding process.

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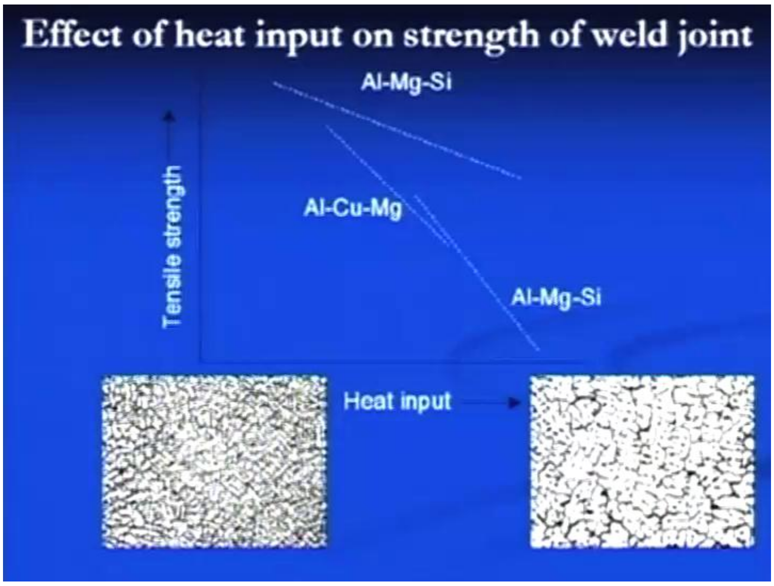

Effect of heat input on this strength of the weld joint - we will see that how it affects - how heat input - affects the strength of the weld joint. Here we can see, that if we consider three alloys - aluminum alloys: one is aluminum copper, aluminum magnesium silicon and other aluminum magnesium silicon alloys - then with the increase in the heat input in all the cases reduction in tensile strength takes place. And it is a normally attributed to the effect of the heat input on the micro structural characteristics, which are produced in the weld joints; like the low heat input leads to the very fine grained structure in the weld metal compared to the weld joints produced by using high heat input.

Here in this micro structure we can see that alpha aluminum light touch to white grains are very coarse compared to the case when weld joint is produced using low heat input. And these micro structural difference is attributed to the reduction in the mechanical tensile strength with the increase in heat input of the aluminum alloys. The similar reduction in the strength of the weld joint of the steels and other metals are also noticed.

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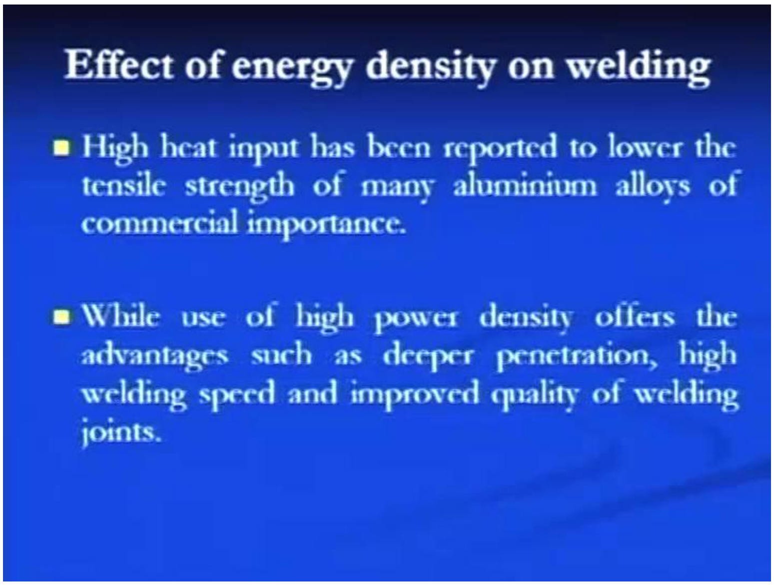

The energy density effect on the welding, we will see, at high heat input has been reported to lower the tensile strength of the many aluminum alloys of the commercial important. While the use of high energy density offers, the advantages such as deep penetration high welding speed and improve the quality of the weld joints.

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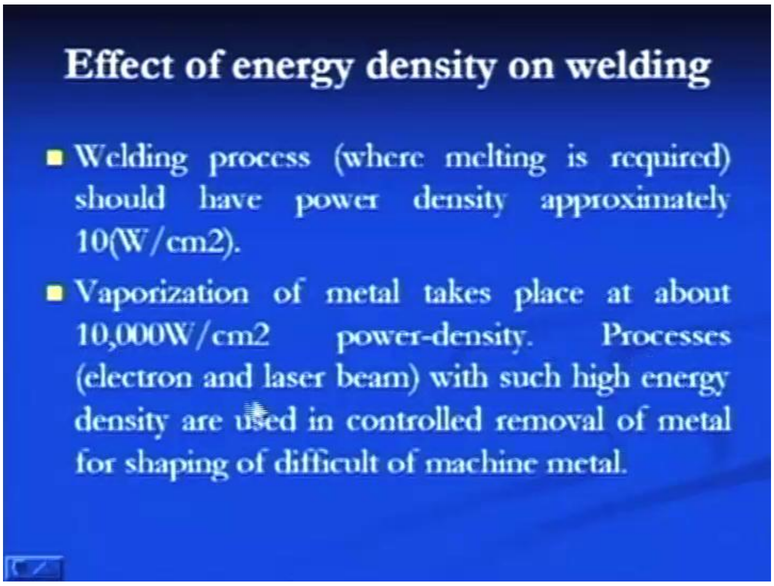

The welding process where melting is required like in all fusion welding processes, the power density should be more than 10 watt per centimeter square so as to get the faying surfaces the molten condition, and to produce the joint.

Vaporization of the metals takes places at about 10,000 watt per centimeter square power density. And this high power density is normally obtained in the radiation based processes like electron beam or laser beam welding processes, where energy density - such a high energy density - is used for controlled removal of the metal for shaping of difficult to machine metals.

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Welding process and their energy density

Sr. No.	Welding process	Power density (W/cm^2)	Temperature (^{0}C)
1	Gas welding	10	3300
2	Arc welding	50	6000
3	Resistance welding	1000	-
4	Laser beam welding	9000	20,000
5	Electron bean welding	10,000	30,000

A comparison of the different welding processes in terms of the power density and the temperature can be seen here. The gas welding is considered a low, is considered as low power density process. It is power density is around 10 in watt per centimeter square and maximum temperature which is generated is 3300 degree centigrade. In arc welding process, it is about 50 watt per centimeter square power density, and the temperature is 6000 - about 6000 degree centigrade.

Resistance welding process is of further high power density around 1000 watt per centimeter square, and the temperature is varying right from the interface to the electrode context surfaces. And the laser welding process offers further higher power density to the tune of 9000 watt per centimeter square, and temperature is also significantly high around 20,000 degree centigrade. And electron beam welding process offers is high power density around 10,000 watt per centimeter square and temperature - maximum temperature - which is generated in this welding process is around 30,000 degree centigrade.

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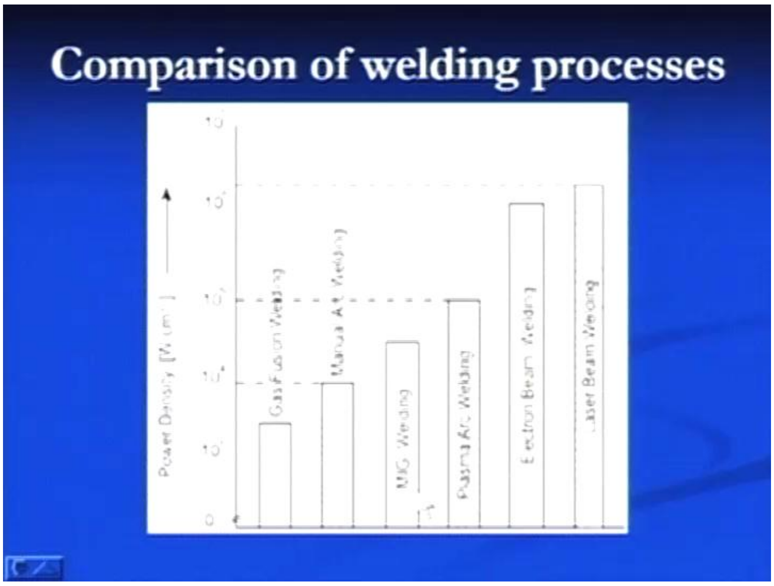

These welding processes in terms of the power density can also be compared here, and it can be seen that the gas welding is the lowest power density welding process and the highest one are the laser beam and electron beam welding processes; while the manual metal arc welding, plasma welding, and beam welding process comes in between.

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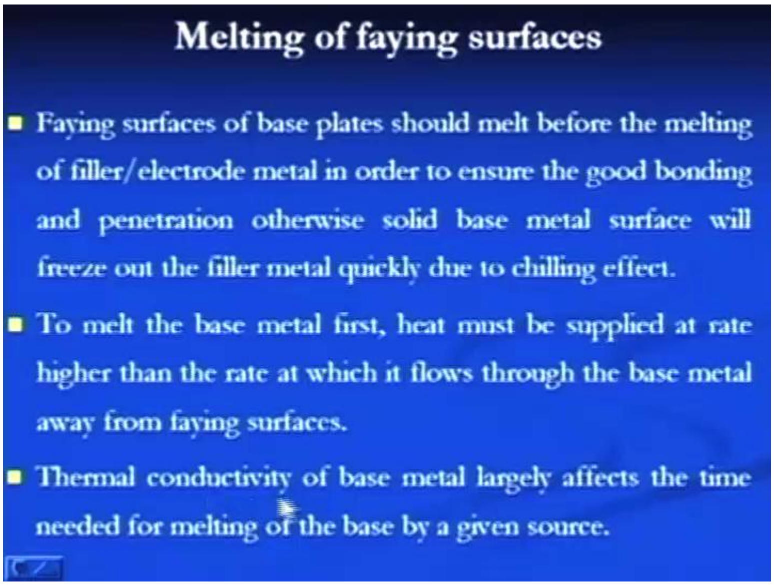

Melting of the faying surfaces is important in fusion welding processes. The faying surfaces of the base metal should melt before the melting of the filler metal or electrode metal in order to ensure good bonding and penetration; otherwise, base metal surface will freeze out the filler metal quickly due to the chilling effect. To have proper bonding, it is necessary that the base metal melts before the melting of the filler metal or electrode metal. To melt the base metal first, heat must be supplied at the rate higher than the rate at which it can be transferred through the base metal away from the faying surfaces. Then only there will be rise in temperature of faying surfaces up to the melting point if heat is supplied at rate higher than the rate at which it is transferred away from faying surfaces. In transferring, the heat away from the faying surfaces, thermal conductivity of the base metal significantly affects the melting point of… significantly affects the time needed for melting of the base metal.

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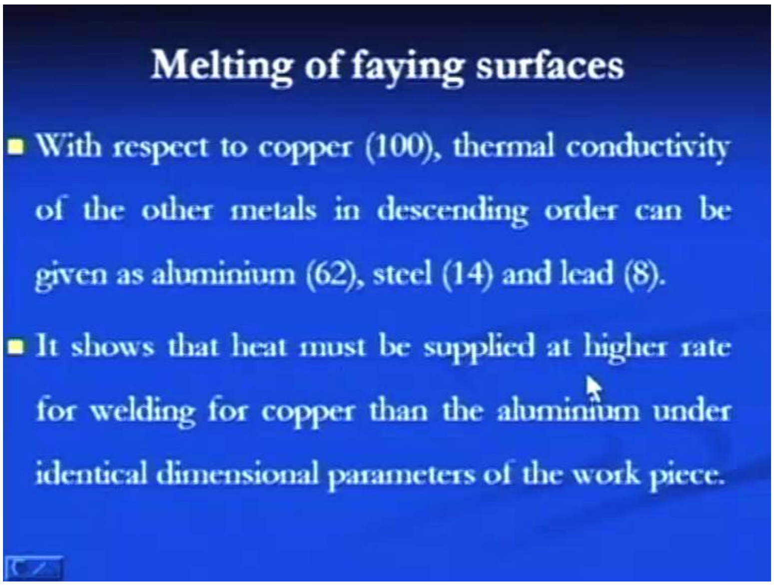

Higher the thermal conductivity, longer the time required for bringing the base metal to the molten condition. If we see the comparison of the thermal conductivities of the some of the metals of the commercial importance, with respect to the copper, thermal conductivity of other metals in descending order can be given as that of aluminum, steel, and lead. On the scale of 100 if copper is given 100 rating, then aluminum is given around 62, and steel 14, and lead 8. Higher the thermal conductivity, longer will be the time required to bring the faying surfaces in molten condition, and greater will be the heat input required to melt the things.

It shows that heat must be supplied at the rate higher - at higher rate - for welding for the copper, then the aluminum under the identical dimensional parameters of the work piece, because the copper having higher thermal conductivity will be transferring away the heat being supplied rapidly from the faying surfaces compared to that of aluminum and the steel. And that is why heat must be supplied at a higher rate for welding of the copper compared to that for aluminum, steel, lead, etcetera.

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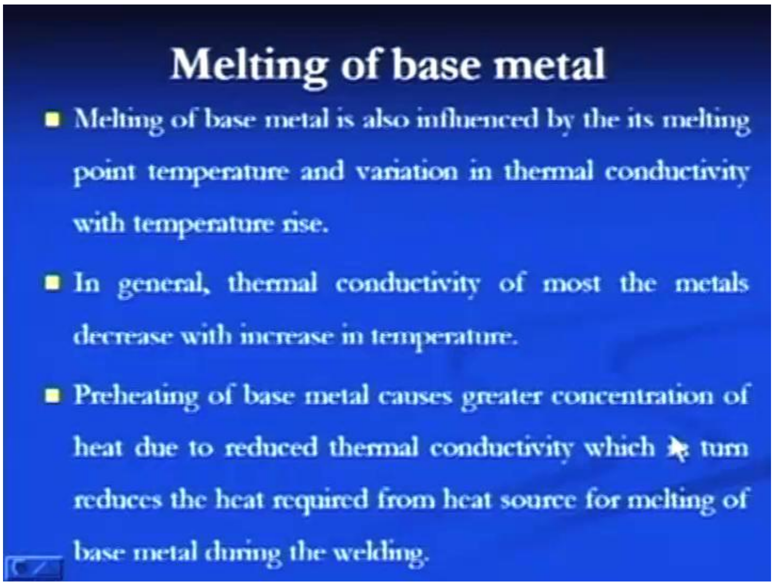

Melting of the base metal is influenced by a number of factors some of them are like this: its melting point temperature and the variation in thermal conductivity of the metal with the rise in temperature.

In general, thermal conductivity of the most of the metals decreases with increase in temperature; and that is why, the preheating of the base metal leads to the reduced thermal conductivity, which in turn causes the greater concentration of the heat, and which leads to the reduced heat input required from the heat source for melting of the base metal during the welding. So, preheating helps to bring the faying surfaces in molten condition, because preheating lowers the thermal conductivity of the base metal.

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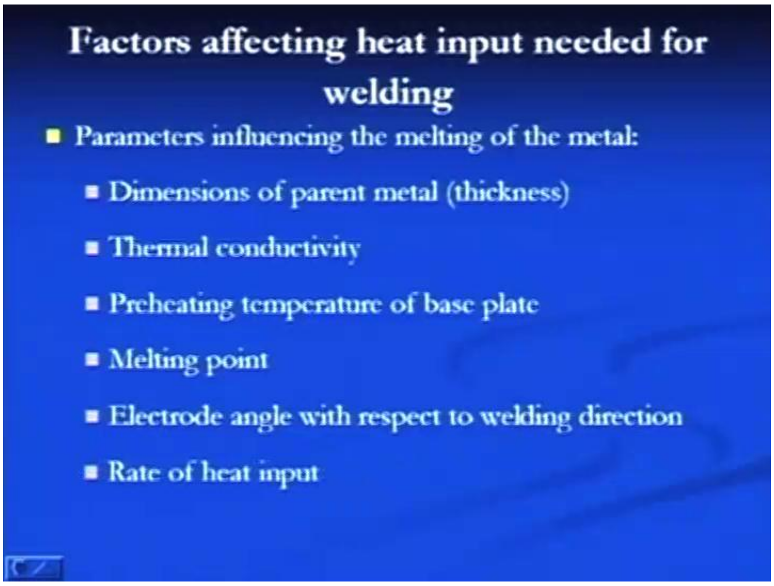

There are number of factors affecting the heat input required for welding. The parameters, which are affecting melting of the base metal, are like: dimensional parameters - dimensions of the parent metal like thickness; greater the thickness, higher the heat input required for the welding process, because heat is transferred rapidly away from the faying surfaces.

The thermal conductivity is another important parameter affecting the heat input. High thermal conductivity, as we have explained - as I have explained earlier - higher the thermal conductivity of metal to be welded, higher will be the heat input required. Then, preheat temperature of the base metal - higher preheat temperature is used for the welding process, then it lowers the heat input required for welding. The melting of the base metal, it is obvious that higher melting point will help to… will lead… higher melting point metals will require greater heat input compared to the low melting point metals.

The electrode angle with respect to the welding direction; the angular position of the electrode during the welding affects the distribution of the heat near the weld pool if the electrode is angled in such a way that it is pointed towards the direction of the welding. Then, it helps to reduce the heat input required for the welding, because the pointing of the electrode to the direction of the welding helps to preheat the base metal, and that in turn lowers the heat input required for the welding. And the rate of the heat input - higher is the rate of heat input, lower will be the amount of the heat required for the welding purpose.

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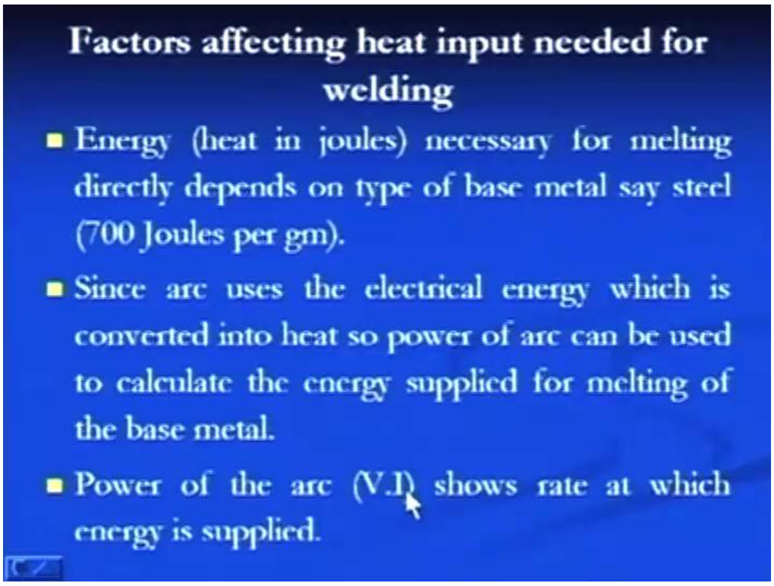

The other factors affecting the heat input like - the energy necessary for melting directly depends on the type of the base metals; say for steel it is 700 joules per gram; like this it may be different for the different metals. So the amount of the heat in terms of the joule required for melting, depends on the type the base metal to be welded. Since arc uses electrical energy, which is converted into the heat, so the power of arc can be used to calculate the energy being supplied in arc welding for melting of the base metal. And the power of the arc is given by the product of V into I - that is the arc voltage and arc current - shows the rate at which energy is supplied in welding.

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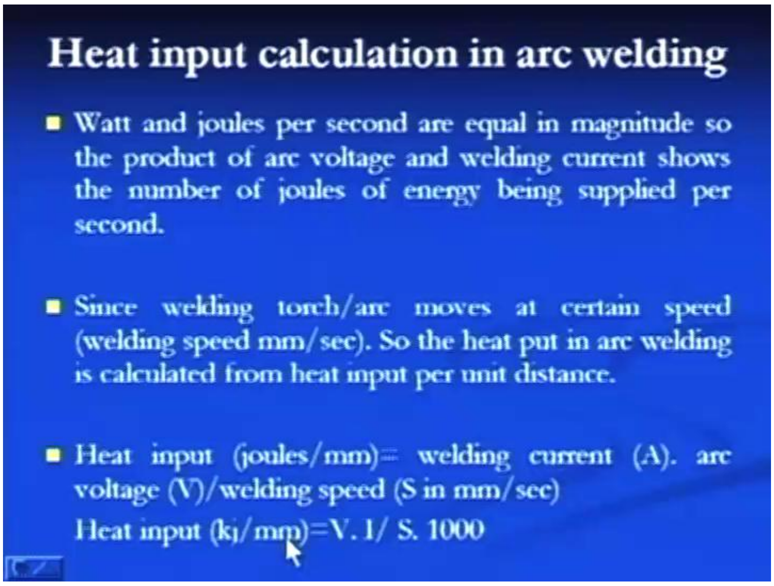

Then heat input can be calculated in terms of the watt or joules per second; both are equal in magnitude; so the product of the arc voltage and the welding current shows the number of joules of energy being supplied per second. Then, here we will see, since the welding torch oblique arc moves at certain speed, say in terms of mm per second, so the heat input in the arc welding is calculated from the heat input per unit distance and the heat input - net heat input - is calculated using the welding current in amperes multiplied by arc voltage in volts divided by welding speed as in mm per second. So, the heat input in kilo joule per mm - net heat input in kilo joule per mm -is expressed as the V into I divided by S into 1000.

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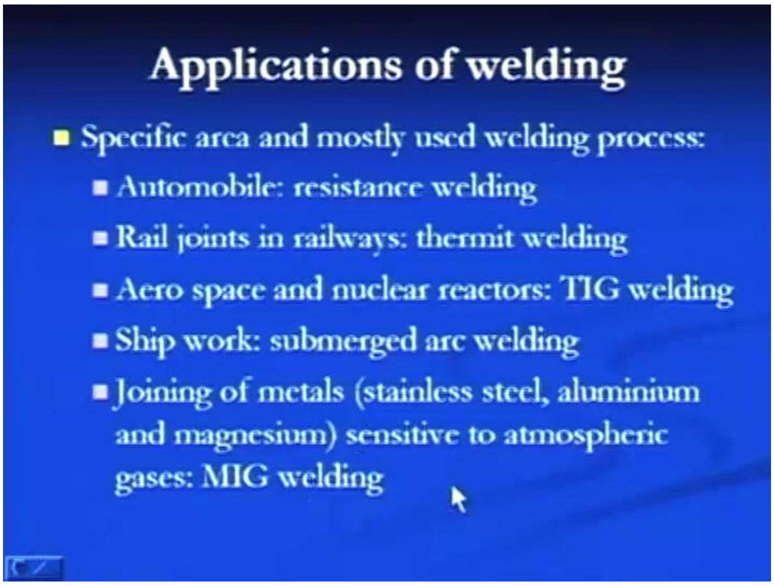

Applications of the welding are very wide and used in variety of the areas, specific areas - a specific area wise there are few welding processes, which are most commonly used like in automobile - resistance welding processes are very common. In rail joints, for producing the rail joints, in railways thermit welding is used. In aerospace and nuclear reactors, mostly TIG welding is used because it is able to produce the reliable - more reliable weld joints. In the ship work, where heavy sections are to be welded, submerged are welding is commonly used. Joining of the metals, which are sensitive to the atmospheric gases like stainless steel, aluminum, and the magnesium - the metal inert gas welding process or gas metal arc welding process is commonly used.

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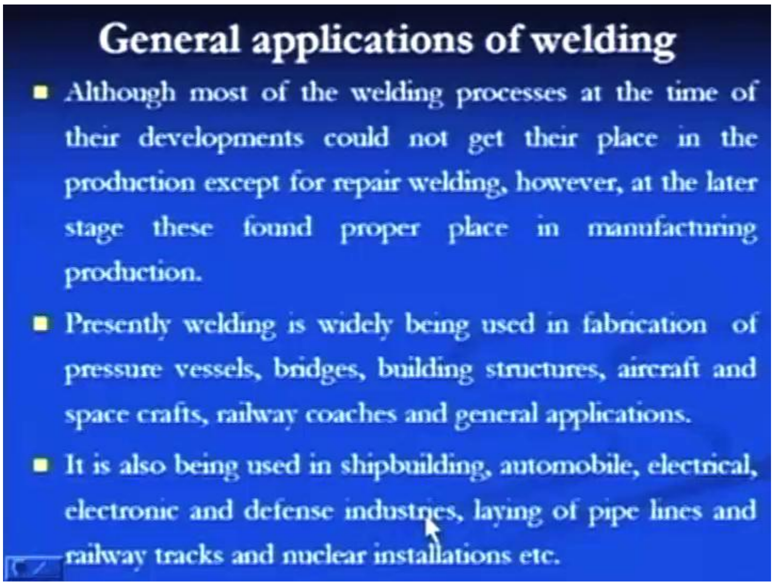

Other applications are like this - initially the welding processes, at the time of their developments could not get their place in the production, except for repair welding. However, at the later stages these found proper place in manufacturing and production. Presently welding is used in fabrication of the pressure vessels, bridges, building structures, aircraft, spacecrafts, railway coaches, and the general applications. It is also being used in shipbuilding, automobile, electrical, electronic, and defense industry, and laying of the pipelines, railway tracks, and in the nuclear installations.

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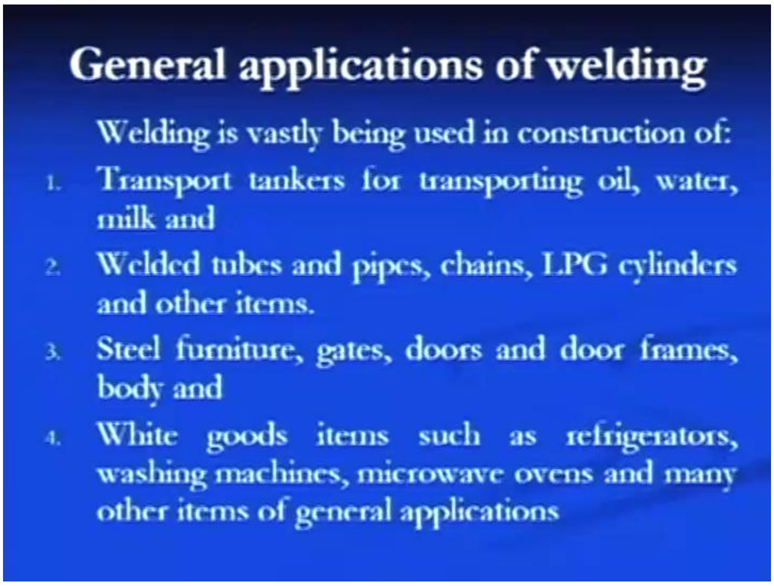

Now, welding is vastly used in construction of the transport tankers for transporting the oils, water, and milk. The welding tubes, pipes, chains, LPG cylinders, and other items. The steel furniture, gates, doors, door frames, and the bodies; the white good items such as the refrigerators, washing machines, microwave ovens, and many other items of the general applications.

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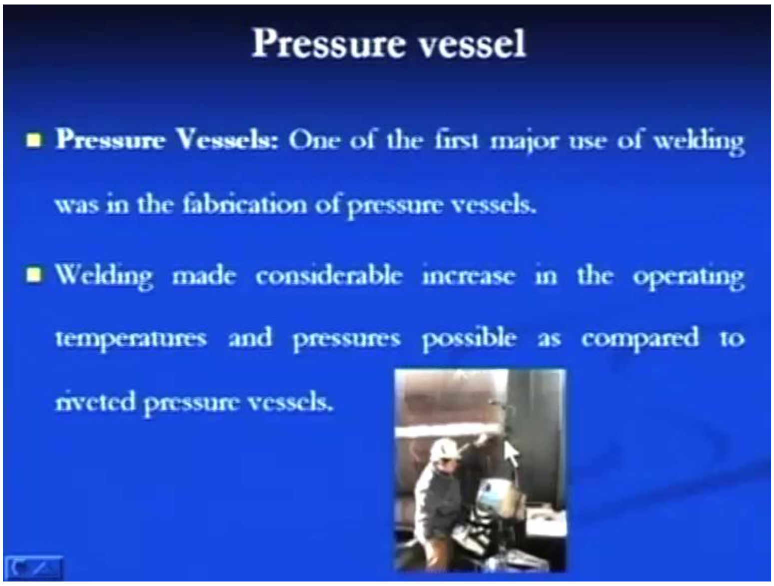

The welding is used extensively in the fabrication of the pressure vessels. Pressure vessels is one of the first major use of the welding, started in the fabrication of the pressure vessels, and welding made considerable increase in operating temperatures and pressures compared to the riveted pressure vessels, and because of these two reasons, the welding is extensively used in pressure vessels. This figure shows that the heavy pressure vessels joined by the welding process and that inspector is testing the quality of the joint produced.

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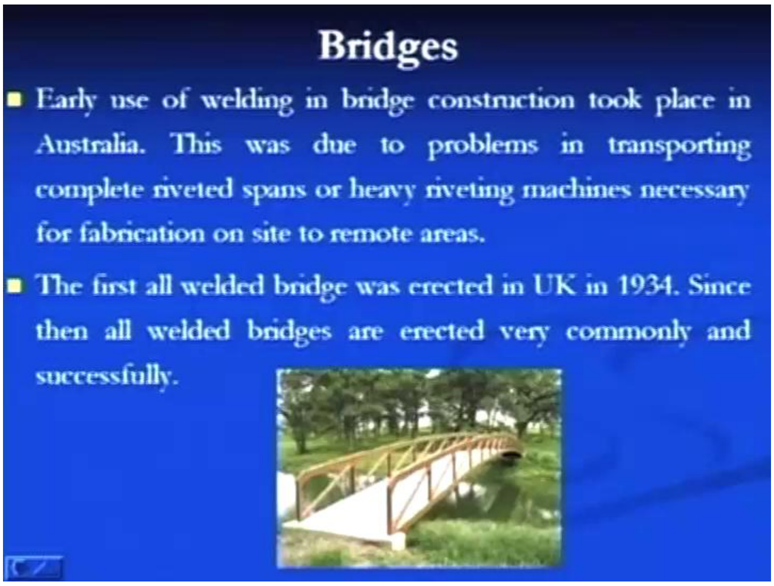

The welding is also used in construction of the bridges. The early use of the welding in bridge construction took place in Australia, and this was done due to the problems in transporting a complete riveted spans or heavy riveted machines, riveting machines necessary for fabrication of onsite to the remote areas. The first of all the welded bridge was erected in UK in 1934, and since, then all welded bridges are erected very commonly and successfully. This diagram typically shows a welded bridge; this diagram shows the welded bridge.

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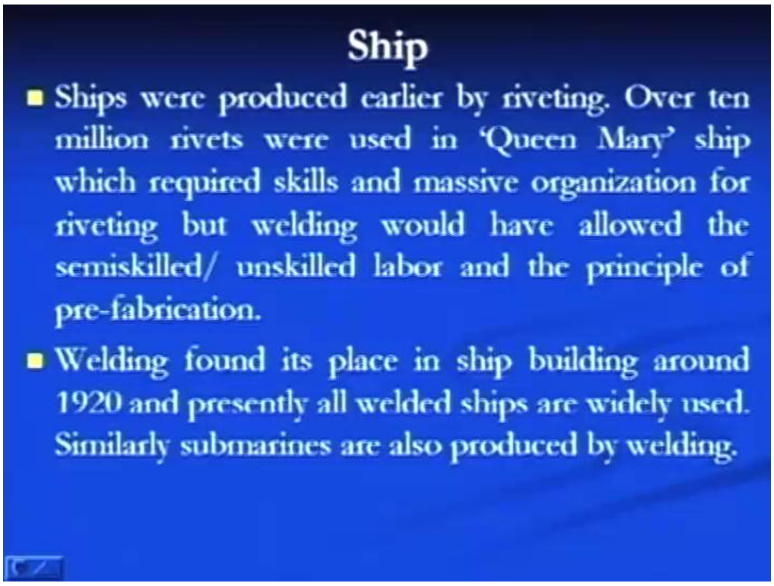

The welding is also used in construction of the ships. Ships were produced earlier by riveting over 10 million rivets were used in Queen Mary ship, which required skills and massive organization for riveting, but welding would have allowed the semiskilled and unskilled labor and the principle of the pre fabrications. The welding found its place in shipbuilding around 1920, and presently all welded ships are widely used. Similarly, submarines are also produced by welding.

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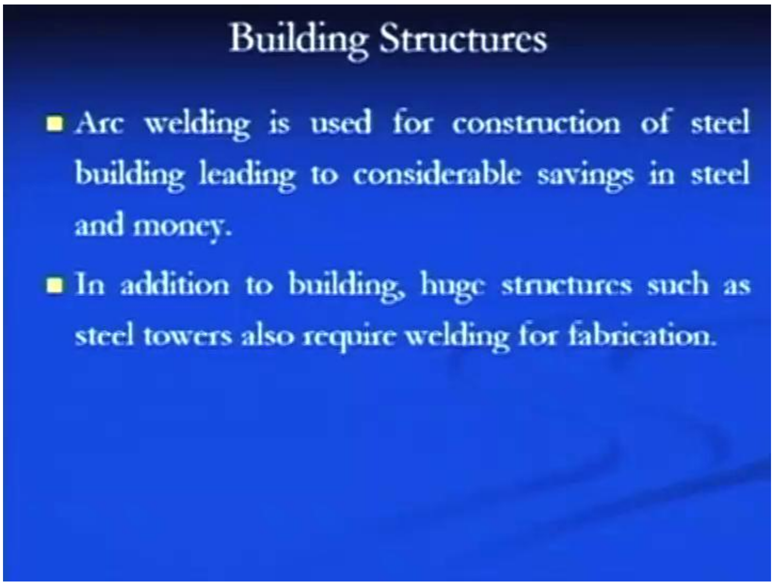

Welding is also used in building structures. Arc welding is used for construction of the steel building leading to the considerable saving in the steel and money. In addition to the building huge structures such as a steel towers also require welding for fabrication.

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Transport industry also uses welding extensively in aerospace; aircraft and spacecrafts - both use welding significantly. Similar to the ships, aircrafts were produced by riveting in early days, but with introduction of the jet engines, welding is widely used for aircraft structures and for joining of the skin sheet to the body. The space vehicles, which have to encounter frictional heat as well as low temperatures, require outer skin and other parts of the special material. These materials are welded with the full success for achieving safety and reliability. And these are the some of the typical components used in a spacecraft industry produced by the welding process.

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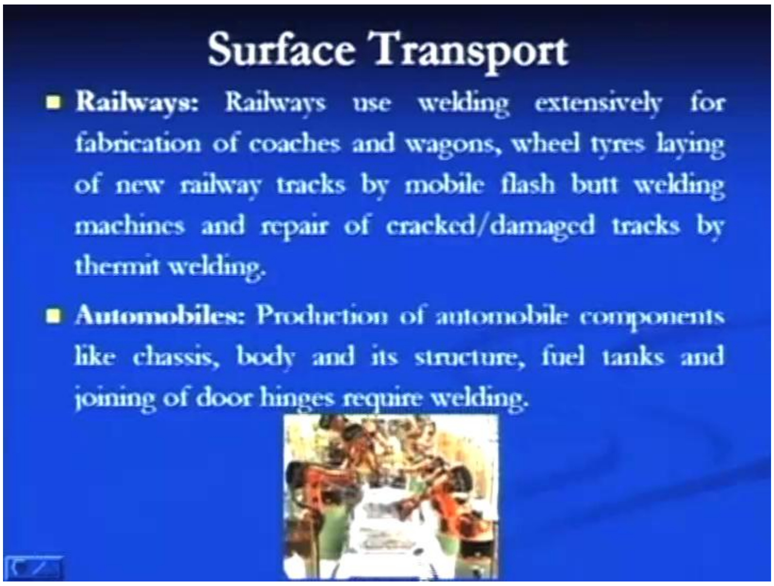

The welding is also used in the construction of the different components of the surface transport industry. Like in railways - the railway uses the welding extensively for fabrication of the coaches, wagons, wheel tires, lying of the new railway tracks by mobile flash welding machines, and the repair of the cracked, damaged tracks by thermit welding. And in the automobiles, production of the automobile components like chassis, body, and its structure, fuel tank, and joining of the door hinges requires welding. And this diagram typically shows the spot welding machines are being used for joining the body parts of a car.

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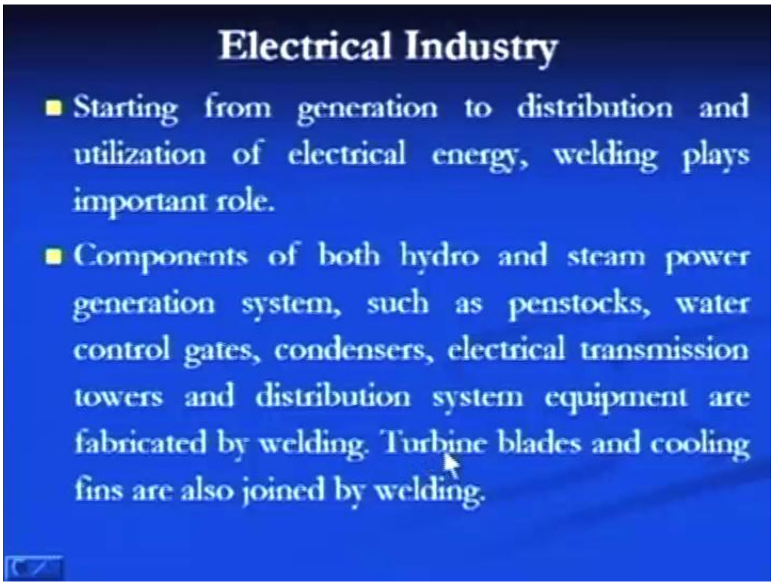

In electrical industry, the welding is also used significantly. Starting from the generation to the redistribution and utilization of the electrical energy, welding plays an important role. Components of both - hydro steam power generation systems such as penstocks, water control gates, condensers, electrical transmission, towers, distribution system equipment are fabricated by welding. Turbine blades and cooling fins are also joined by welding.

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In the electronic industry, welding is also used significantly now-a-days. Electronic industry uses welding to limited extent for joining of the leads of the special transistors, but other joining processes such as brazing, soldering are widely being used. The soldering is used for joining components to the printed circuit board - PCBs - and robotic soldering is very common for joining of the parts to the printed circuit boards of the computers, televisions, communication equipments, and other control equipments. And this shows the typical diagram of the ultrasonically welded, ultrasonically joined electronic component, and this is the PCB, which is joined by the soldering process.

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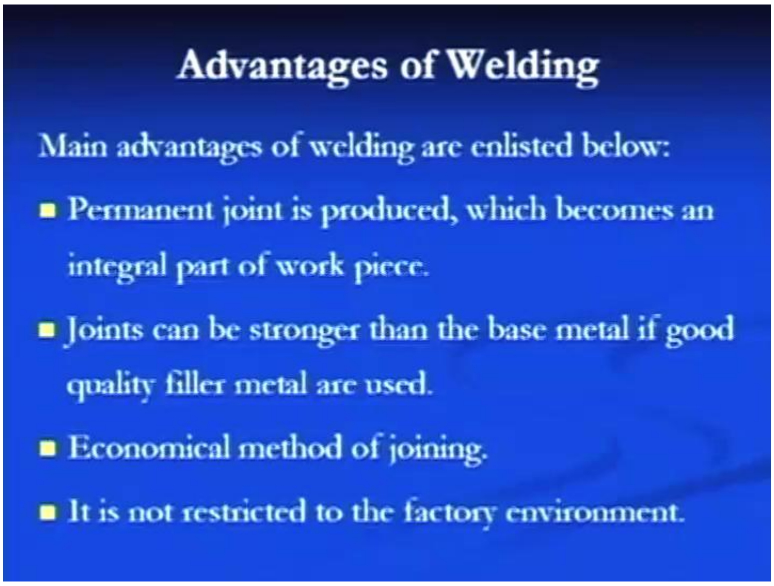

The advantages of the welding process we will see now. The main advantages of the welding processes are given below: the joint produced is permanent one which becomes an integral part of the work piece; and the joint can be stronger than the base metal, if the good quality filler metal is used; and the economical method welding is very economical method for joining the components; and the welding process is not restricted to the factory environment, the system can be taken to the on-site also.

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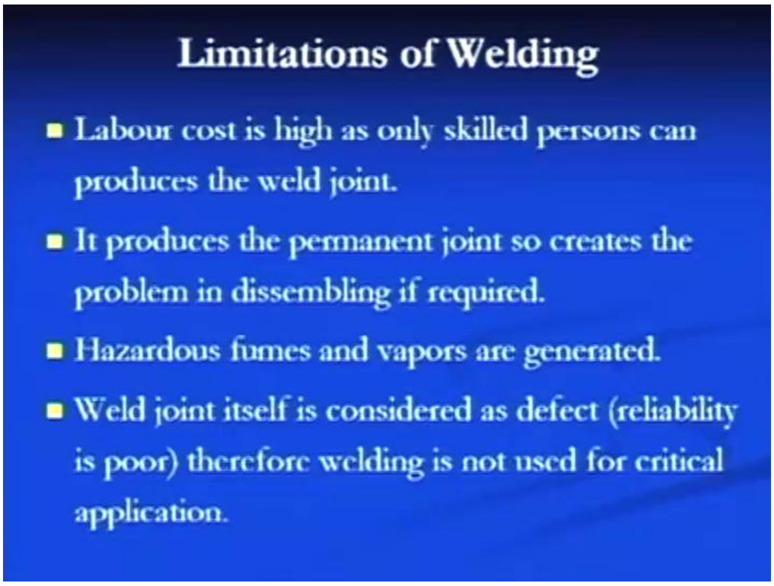

The major limitations of the welding processes are such as - labor cost is high because mainly skilled persons can produce the reliable weld joints; and it produces the permanent joint, which creates problem in dissembling if required; and hazardous fumes and vapors are generated to during the welding - so that is harmful for the health of the workers; and the joint itself is considered as a defect that leads to its poor reliability. And therefore, welding is a not preferred for the critical applications. Now, I will summarize this lecture. This was the first lecture on introduction of the welding processes, and you have seen the various aspects related to the welding like the power density aspects, and the applications of the welding processes. Now, this is a first lecture of 12 lecture series based on the welding. Now, in next few lectures, we will see if the welding process classification, and the various technical aspects, and the principles of the specific welding processes.

Thank you for your patient hearing.