Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology- Part-1

Module- 46

by
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Hello and welcome to this manufacturing process technology part 1 module 46.

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Today we will be mostly talking about the joining processes particularly the different solid and liquid state welding processes and in that we will try to understand the physics of welding will also try to describe some of the associated designs that are involved in planning a welding design, so let us look at all the joining processes and why it is necessary, okay.

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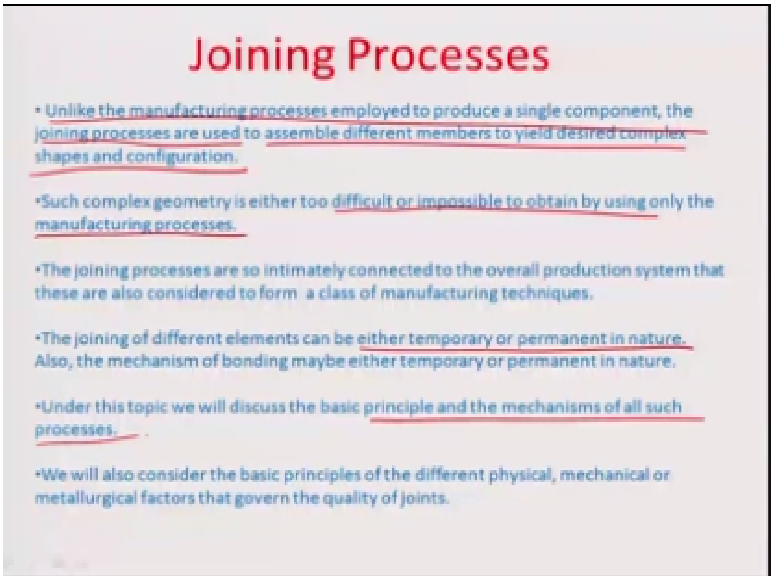

So unlike the manufacturing processes employed to produce a single component, the joining processes are used to assemble different members to yield complex shapes I think I had earlier described that you know when you talk about assembly obviously there is has to be relative orientation between the various parts or components before that joining is a very, very important issue.

So sometimes the geometries that are involved in plugging these components together are so difficult or so impossible to obtain by using only the manufacturing processes etcetera therefore joining processes aware maybe two or more components are joined together to realize one particular link is employed for the benefit of you know reducing the complexity of the manufacturing processes, so therefore joining is extremely important as a process.

The joining of different elements can be either temporary or permanent in nature also the mechanism of bonding accordingly may be either temporary or permanent. So for example, in case of you know nut and bolt kind of system which is joining or maybe screws which are joining two members in an assemble we can easily open or close based on our convenience and it can be recorded as a temporary joint. Whereas something like let us solid state welding where there are two components which are pressurized very close to each other so that there is some kind of bond formulation between them maybe easily recorded as a permanent joining process,.

So that is how you classify and this is a first classification for all the different joining processes, so we will basically describe some of the principles and the mechanisms in all such processes and with the physical or mechanical point of view and also some other metallurgical view points which emerge while studying such joining processes would be treated in this particular area.

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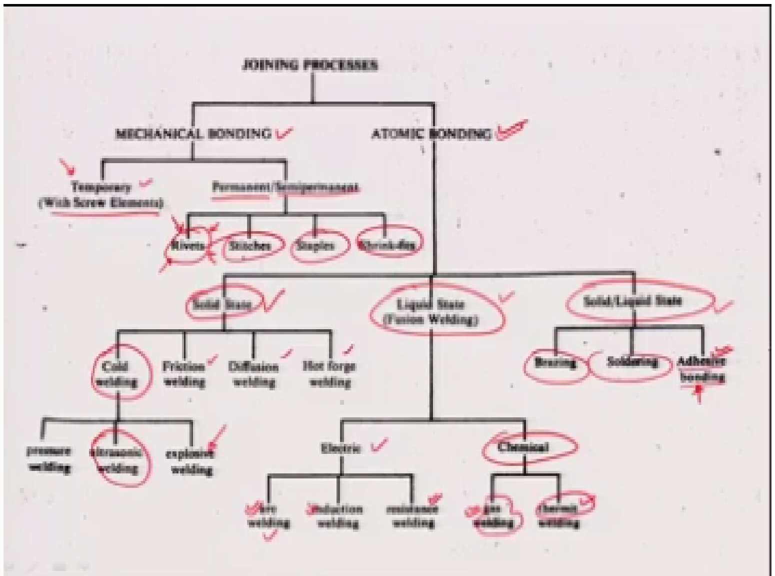

So let us look at a classification schematic of the various joining processes so typically joining process can be classified into mechanical bonding and atomic bonding, mechanical bonding could be again classified into permanent or semi permanent kind of joints and a temporary with screw elements for example as I just mentioned earlier. In the permanent semi permanent category there can be reverting, there can be stitching between two surfaces or stapling between two surfaces or you may shrink fits sometimes which ensures that you have some kind of semi permanency between the joints that means if for example in the case of rivets without destroying the rivets or without breaking the rivets open you cannot really undo the joining process.

So it is some kind of a semi permanent intermediate kind of a joining, so therefore that is how semi permanent joints can be interpreted. Now the other type of joining happens more on a atomistic bases where you can have two crystals for example where two different materials for example taken so close to each other by visual of pressure and some deformation that there is some kind of a cold weld which is formulated within the two surfaces.

So such surfaces are or such kind of bonding is also known as solid state bonding there can be again liquid state bonding and bonding can also be solid and liquid state I will just explain some of the solid state bonding. So one of the examples you know could be cold welding where two members two metallic plates for example I have brought very close to each other and applied with certain pressure.

So that the distances between the surfaces become almost equal to that of a grain boundary, so there is automatically a increase in the atomic forces because of probably the electrons of one set of atoms attracting the, getting attacked by the nucleus of the other set of atom, but that close proximity or close distance between the surfaces need to be coming for this kind of a bonding to take place.

There can be again cases of ultrasonic welding where you vibrate one of the compounds one of the members and ultrasonic frequency so that you can again introduce proximity between the members in a manner so that there is a solid state bonding which takes place. You can also in this category introduce exclusive welding, similarly other solid state bonding phenomena or friction welding diffusion welding hot forge welding so on and so forth.

In the liquid state and fusion welding processes you typically use a source of heat so that you are able to either melt the parent material or a different material together for introducing the bonding between the two, so in the liquid state particularly you can actually use an electric arc okay, where what you normally do in arc welding and there is a arc established between an electrode and a surface which is very high power and high power consuming and it generates stream of electrons which completely melts the parent materials together so that there is some kind of a melting and solidification, re-solidification which would ensure the bond ability to be same.

So the electric source can either be an arc where you can record this is an arc welding process it could be electromagnetic induction causing any currents which would lead to the local heating of the material particularly metals. so then either induction welding or resistance welding where there is a pressure as well as a strong current between the sheets that are being joint or the two members that are being joint which results in a local heat increase and a local melt pool between both the sheets.

The other forms of liquid state welding as basically the source changes from electrical to a chemical source. it could be either a hot flame producing produced by a gas or by the transition metal oxides and aluminum fuel particles together known as thermites and the heat source in a gas welding typically is an oxyacetylene flame which causes film material to melt and go into the two heats and then it re-solidifies to formulate the weld ment.

So there are other cases of particularly solid, liquid state welding for example let us say adhesive bonding where there is an adhesion layer which is applied between two different solid material so without really changing the state of the materials into a liquid form the adhesive layer which itself being liquid when it dries up it introduces bonds between both the layers they may be of temporary type but that those bonds are also considered to be good enough for weldment.

For example, you can actually bond plastic to metal which is one of the key things in automotive industries which is based on adhesive bonding, you have soldering and brazing where again the film material is basically taken to its melting temperature and it generates some kind of local melts in the periphery of the weldment and there is some kind of some degree of diffusion into of the welding zone in the periphery which results and again re-solidification and joining between both the solid members, okay.

So these all examples of classifications of different joining processes, so having said that now let us look into a little more fundamental aspect about joining processes.

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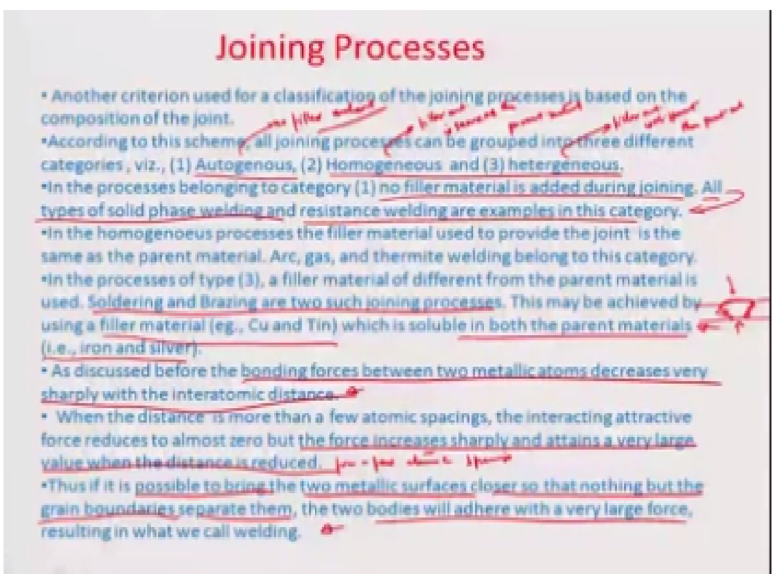

And let us try to first classify into various schemes based on different modalities. let us talk about the classification of welding into autogenous, homogenous and heterogeneous processes in category . an autogenous process no filler material is added during the joining all the types of solid phase welding and resistance welding are booked into this category so there is no filler material, then there are homogeneous joining processes where the filler material that is used the same as the parent material.

So filler material is same as the parent material and then obviously there are heterogeneous processes where the filler material maybe completely different, is different okay, so these are the soldering and brazing related processes where it may necessary that the filler material is same as the parent material it is different than parent material, so soldering and brazing for example at two such joining processes where the filler material in one case is copper and tin.

Another iron and silver and both of them are soluble in the parent material so therefore there is a zone of local melt which is created inside the parent material where there is some kind of a you know sort of solubility and diffusion of the liquid metal or the liquid filler and then when it re-crystallizes it re-crystallizes as one whole and joints both the sheets in this particular case or both the members in this particular case.

So as discussed prior to this in the section n materials we had illustrated how the bonding forces between the two metallic atoms decrease very sharply with the inter atomic distance so obviously as we have recorded earlier that if the inter atomic distance changes to almost a single atomic spacing there is a tendency of the electrons of one of the atoms to be attracted towards the nuclei of the neighboring atoms, so these interacting forces are very, very large which results in a very strong bond between the two particularly when the two atoms species are displaced to a distance of or more or less the inter atomic spacing between the or the lattice spacing between the two atoms of the lattice.

So the force sharply increases and attains a very large value when the distance is reduced from a few atomic spacings. Thus, if it is possible to somehow bring the two metallic surfaces closer so that nothing but the grain boundary separate them the two bodies will adhere with very large forces okay, and that is what we call welding okay. So how to do this and how, what kind of mechanisms are deployed are basically again part of solid state welding processes.

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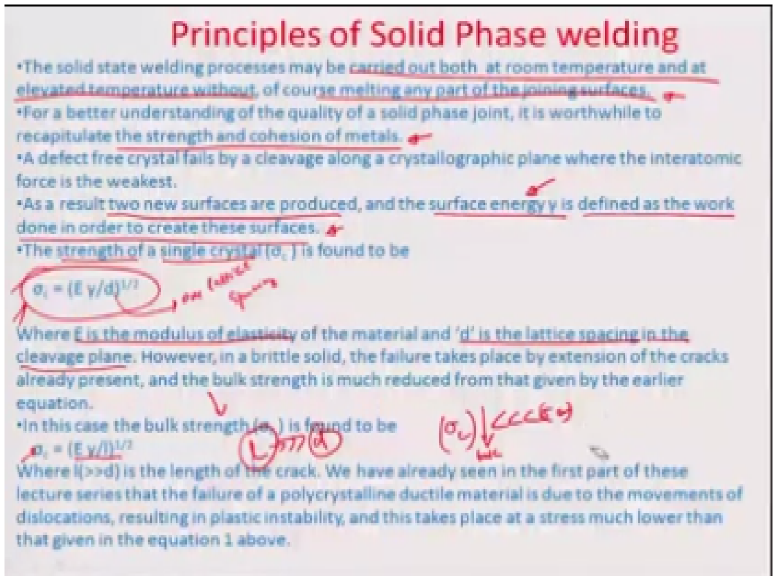

So in a solid state welding process basically which we can carry out the welding particularly at room temperature and obviously also at an elevated temperature but without melting any part so okay, so still there are surfaces which have solid surfaces they do not loss their integrity and you know you can basically apply a pressure as well as heat here to perform the welding. So for a better understanding of the quality of the solid phase joint it is worthwhile to recapitulate the strength and cohesion of metals, okay.

So a defect free crystal normally fails along a sort of a crystallographic plane where the inter atomic force is the weakest okay, so that is how there is a development of a crack so wherever there is a case where the inter atomic force is the lowest value and supposing you are now putting the object to a tensile strength the failure would happen from that area where the bond between the material is the weakest.

What happens after the failure takes place so the two the material is separated along a crack portion or let us say around a small kind of fissure and there are two new surfaces which would come into existence and therefore the surface energy should increase because of the creating of two of these surfaces, okay and the two new surfaces which are produced would let us say demonstrate surface energy γ.

And you know this energy is basically defined as the work done in order to create those surfaces which you are doing externally obviously you are pulling the material to get this crack initiated or get this you know fissure initiated between the material so whatever energy you are applying to the system is getting in terms of formulation of those new to surfaces okay, along which the crack has actually formulated.

So in a single crystal level if we wanted to gage what is the strength σ_c of such a pair of surfaces created the σ_c happens to be given by $(E\gamma/d)^{1/2}$ where E is the modulus of elasticity of the material d is probably the lattice spacing okay, so this is actually one lattice spacing we are talking about crystalline materials and particularly one lattice spacing in the cleavage plane that is what is of concern to us.

And think of it that in brittle solids the failures take place by extension of such cracks so therefore there is if supposing some kind of a twin surface here is created it basically extend itself in a certain direction and we say that this is because of the crack propagation process so therefore the along that particular line they develop several such inter atomic spacings where there is a new surface which starts get in created okay, and so there is a complete cleavage plane which is formulated which maybe more than a few lattice spacings in length okay.

So in that case the σ_c which comes out or the bulk strength of the material which comes out is given by again $(E\gamma/l)^{1/2}$ where this l which I just told you is much, much, much greater than one lattice spacing so the crack is around let us say five different lattice spacings or even more 50,000 more lattice spacing, so it is a relatively larger entity in comparison to a single cleavage plane created across a single crystal where the question is only of one lattice spacing.

So obviously the σ_c reduces because of that right, σ_c in case of crystal is inversely proportional to $d^{1/2}$ in this case it is $l^{1/2}$ and l is much, much larger than d so obviously the σ_c would be much lower in case of bulk materials okay, then in case of crystals. So σ_c bulk is much, much lower in comparison to σ_c crystals, okay and so that gives you a bases of why solid welding processes would happen okay.

So we have already seen in the first part of our lecture very appropriately that the failure of a polycrystalline ductile reptile material is typically due to the movements of what we call dislocations which will be available over only one or two or maybe a little more size lattice planes and this planes are sort of misfitted into the overall lattice because of which you can say that there is a tendency of the failure of the polycrystalline materials.

So if all the dislocations move together in certain space there is tendency of the energy in that region to go high because of which the material will start breaking down and there is plastic stability because of this, okay.

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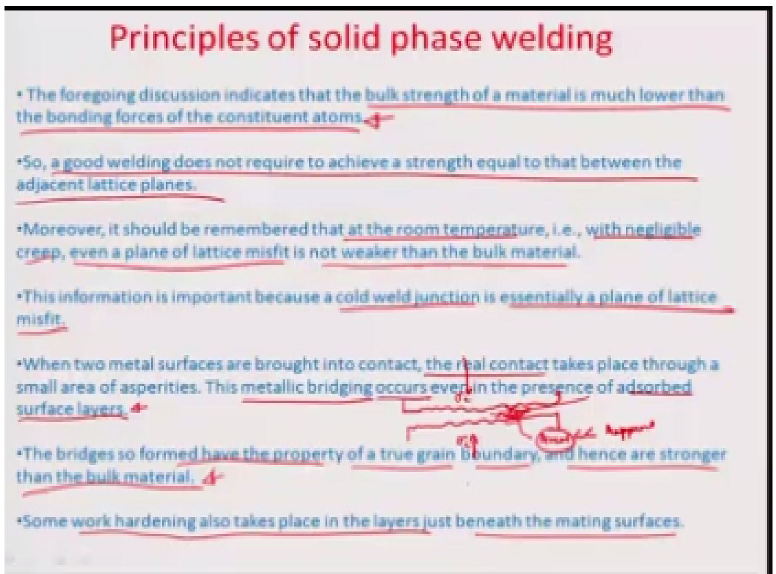

The foregoing discussion indicates that the bulk strength of the material is much lower than the bonding forces of the constituent atoms we just had an idea that in one case the total amount of ultimate yield strength σ_c is proportional to the inverse of $d^{1/2}$ another $l^{1/2}$ and l is very, very greater than d. So σ_c enviously is a lower in value in case of bulk material, so think of it that when we talk about a joint strength it is about how the material would arrive and its ultimate yield strength when there is some kind of a crack or separation or something with starts play taking place between the different planes of the materials.

And in this particular case we are talking about a situation where we are comparing the lattice misfits okay, because of the pressure generated between two surfaces where the distance is coming very, very close to that of almost grain boundaries so meaning thereby that the two surfaces that we are pressing in the solid welding is coming by a distance closer than almost one or two lattice spacing, so obviously that force would be much greater or the yield strength and that particular region because of that lattice misfits of a few planes between the two surfaces would be much, much greater in comparison to the bulk strength of the materials.

So obviously when in such a case if we pull the material from both sides the failure will take place along any other region of the bulk but not on the interface, so that is what the solid you know welding strength is defined as just because in a crystalline level the ultimate yield strength increases much more in comparison to that amount of bulk level. You can say that a plane of lattice misfits because of this kind of a pressure where the surfaces come close by almost like a grain boundary thickness difference is attains a more larger value in comparison to the overall bulk strength the material.

So good welding does not require to achieve a strength equal to that between the adjacent lattice planes, and you must remember that at room temperature the, with negligible creep even a plane of lattice misfit is not weaker than the bulk material, okay. So in a cold welded junction it is essentially a plane of lattice misfit which is inserted between the two melting surfaces at a huge pressure and so the contact if we look at between the two planes which are being brought close together let us say we ask welding these two surfaces with respect to each other with respect you know applying a vertical pressure in between the two.

So there are these small, small asperities is between the surfaces which kind of formulate the real contact okay, and the metallic bridging kind of a thing happens here that supposing there is one contact which is like a hell another which is again like a hell so there is some kind of a when it joints each other obviously the real area which is there as I think I had earlier mention a very appropriately in case of study of friction is much, much smaller so the A_{real} smaller in comparison to the a apparent you know the apparent area really is that of the surface and the real area is very, very small.

So in this region it is very easy to come you know for the overall stress to come to the plastic deformation and there is some kind of a deformation of these two asperities which results in a cold one and because obviously you have brought them closer than the you know and so that the bell bulk strength is kind of exceeded at that particular level and this metallic bridging occurs even though if there are some kind of an adsorbed surface level like an oxide or some oils etcetera presents still this metallic bridging occurs very well, okay.

So the bridges so formed have the property of a true grain boundary and hence they are stronger than the bulk material as I had earlier illustrated and also there is some work hardening which takes place in the layers just to beneath the mating surfaces so overall the weldment in this particular region because of the work hardening under beneath and the strength here of almost single crystal becomes much larger in comparison to the bulk strength of the two materials σ_c. So therefore, it is considered to be a good weldment.

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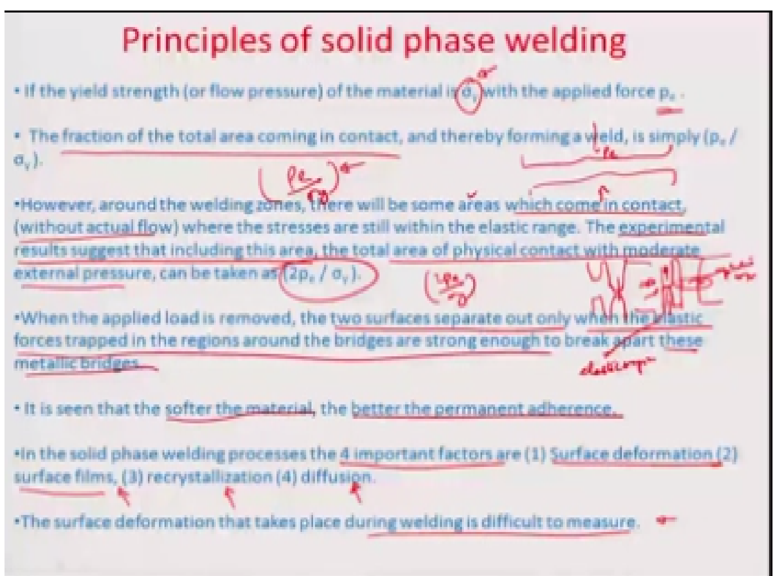

So let us look at the series of events which happen in such processes so if we consider the σ_y to be the bulk strength of the material or it is the yield strength of the material and we apply a force

p_e over these two surfaces which we are bringing close to each other so this force is p_e, so obviously the fraction of the area which comes in contact by formulating the weld can be easily given by p_e/σ_y okay.

And however around the welding zones if I look at really how this asperity is getting deform so the asperity earlier was present like this and when we have touch the asperity the slight deformation happens okay, and then there is some kind of a local weld which is taken place here, so there will be some area which we will come in contact without the actual flow as well. Supposing there was an area just close by whether the height was not so significant as the plastic flow would happens.

So supposing these two get welded together and it may be possible that these two just about start touching each other very close to the surface here okay, so there is obviously quite a bit of that area which is not so high so that plastic deformation would occur but still they will touch each other when the plastic deformation may happen across some of the let us say top order asperities with higher heights or higher larger heights on the surface, okay.

So here we can obviously say that these areas which have just coming contact without any plastic flow would still be in the elastic region, so this is a elastic region okay, and this obviously is a plastic region and so really whether the two surfaces would separate or from each other would depend on whether these elastic forces are greater enough to pull apart the plastic deformation and weld ment which has being formulated so if this area were very, very high in that event obviously these surfaces would come closer.

But the elastic range material if it is not able to given sufficient amount of so sufficient amount of recoiling force so therefore it will not really change anything and the weldment will remain in that. So experimental results suggest that you know if we include this area the total area of physical contact with moderate external pressure comes out to be about close to only twice this $2p_e/\sigma_y$ you write, σ_p/σ_y was the area which was the plastically deformed asperity area.

But the overall area then becomes $2p_e/\sigma_y$ when the applied load is removed the two surfaces separate out only when the elastic forces trapped in the region around the bridges are strong enough to break apart these metallic bridges if does not happen the weld ment would the remain as such. So obviously for softer material so the deformation level is much, much higher it results in a better or a permanent adherence because more or less this elastic force may not be that critical as a number of areas which would have yielded into the plastic range would be much higher you know in a softer material then in a harder material.

So in the solid phase welding process 4 most important phenomena of factors are associated one is obviously the surface deformation the other is surface films we sometimes promote or heat or which sometimes promote the separation between the surfaces and does not allow the contact to take place, it may be brittle film for example and oxide film where there maybe some local crack propagation which happens where the strength aspect of bulk verses weld ment the theory may not hold to any more.

Then is there is also re-crystallization which may happen because of pressure driven heating of give to their pressure driven deformation I am sorry, of the different grains and then obviously diffusion which is migration because of concentration gradients between the two surfaces, one surface is the higher concentration of a certain material in comparison to the other obviously there would be some diffusion through the solid state happening when it comes closer to each other.

So the surface deformation that takes place during welding is quite difficult to measure although some estimates can be brought out.

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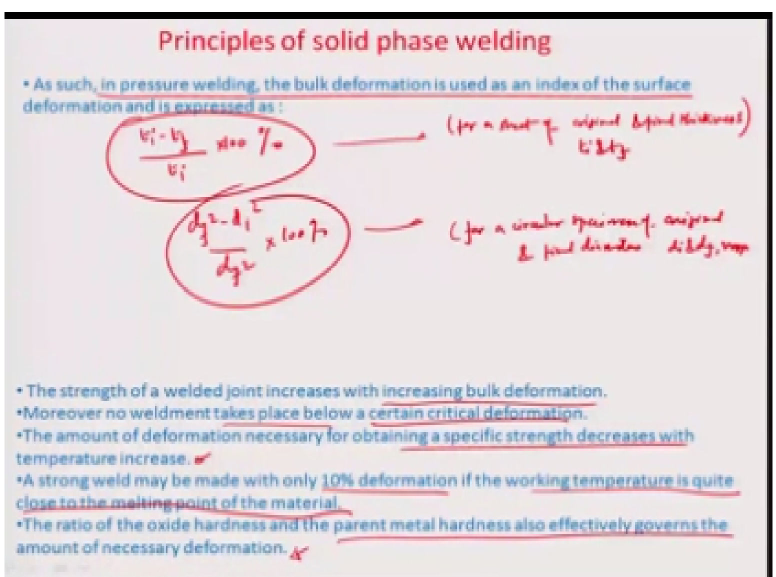

And as such in pressure welding the bulk deformation is used as an index of the surface deformation so if I say for a heat of original and final thicknesses t_i and t_f .I want to measure the bulk deformation, I would simply write this as t_i-t_f/t_i expressed as a percentage and for a heat of or for a circular specimen of original and final diameters or a circular specimen of original and final diameters di and df this respectively would become d_f^2-d_i^2/d_f^2 as a percentage okay, so that is how you express the surface deformation of either flat sheets or around objects.

The strength of a welded joint increases with the increasing bulk deformation and no weldment would take place below a certain critical deformation happens in the amount of deformation necessary for obtaining a specific strength decreases with the temperature increase and obviously a strong weld may be made only with 10% deformation if the working temperature is quite close to the melting point of the material.

Also the ratio of the oxide hardness and the parent material hardness effectively governs the amount of necessary deformation which would happen in solid phase welding. So the greatest hurdle which comes in case of solid phase welding are the oxide layers and so what you know and or may be some kind of oil films or some kind of separation films which would not allow the weld ment to happen by making an intermediary their either which would have a crack propagating effect or would probably have some kind of you know oil or impurity allowing not allowing the two materials to come to the closeness of that of a grain boundary

So the many methods which are used for taking care of such situations for example you can scratch over as the oxide layers on the top of the surfaces which you want to solid weld on this particular manner, so that you still have you exposed the material below it or may be neither with washing techniques or with some kind of you know etching techniques remove away the layer of lubricant or the layer of the oil which happens to be a part of the sheet because of its forming process associated with the easier die-removal etcetera.

So there are many ways of sort of ensuring that you do not have the oxide or the intermediate oil layers for doing a good solid phase welding. So we would like to continue further in this area but in the interest of time I would like to close this particular module in the next module we will talk little more about just extension of whatever we have studied so far followed by studying of different sources which would be important for us to analysis the liquid state welding particularly and sources of heat would be something like let us say electrostatic arc welding and how do we really design for a good power system etcetera which would do the welding properly and effectively, with this I would like to end this particular module thank you so much for listening.

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