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Environmental Degradation of Materials

Lecture – 22
Broad Subject: Anodic Protection, Forms of corrosion, Factors of corrosion

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So we see that anodic protection depends on the passivity of metals and alloys, and it also depends on the anodic polarization from the free corrosion potential, and this method is not applicable in case of active metal where we do not see any active passive transformation, and if we go towards the anodic polarization side we will see that the current corresponding to anodic dissolution keeps on increasing, and that actually increases the corrosion rate of the metal what we are trying to protect, but if it is the passive metal then the corrosion rate can be reduced to a great extent of the order of 5 to 6 orders, and the current value what we need to supply in order to maintain that passivity would be very, very small.

Now let us have some sort of idea on the basis of value, some numerical value, now we have seen that the anodic polarization does lead to anodic protection in case of active passive metal and this is potential access and this is log I, and so this is for active passive metal, and if a metal which is, this is my I0 for that metal on the metal surface, and this is my IA for metal going to metal N+ iron, and this is my IC which is the cathodic current density, and this is my free corrosion potential and this is my I Corr, and this is my E Corr.

Now the potential of the metal is at this point, and now we have to increase the potential of the metal towards the positive side, and if this metal is active passive metal so initially the current value increases and then once it reaches to I critical, I critical it takes a reverse turn. Now when it takes a reverse turn that time it goes under unstable passivity and gradually the oxide layer or the passive layer is growing on the surface and finally it maintains a almost parallel line corresponding to the potential axis and this is my active passive metal characteristics, polarization characteristics and I am going towards positive side.

Now if this value is around 10 to the power 2, 10 to the power 2 and let's say this is 10 to the power 2 milliampere per centimeter square and this is in milliampere per centimeter axis, this is milli ampere per centimeter square, now let me put some value this is in log scale so this is my 10, this is 1, then this is 10 to the power – 2, 10 to the power – 3.

Now initially if I go towards the positive side my applied let's say I have reached to this value when my polarization is Del E1 and that time my applied current density 1 and I applied 1 is nothing but IA - IC, so if I keep going towards positive direction I see that IA is increasing and my I applied is also increasing, that means I need to spend a lot of current in order to go to the positive side and we are not getting any benefit out of it because we see that IA is increasing, but gradually if we keep on increasing like this we can reach to the value corresponding to the critical, I critical which is I critical = IA dashed, that value if we reach that is the maximum applied current we need to apply, this is maximum I applied max according to this figure, and that time my current density corresponding to the anodic polarization, anodic current or anodic current density is the maximum, now if we increase it little more let's say I have reach to this place so I see my I applied would be this much, but what would be my IA, IA would be this one and which is IA is equal to IP, IP means I passive, the current density corresponding to the passive range now since this is very close to the unstable passivity region so let me move little further, okay, so I move little further on the positive side and I reach to a very, very stable passive range and that time my I applied is this much. So as we go up we see initially I applied increases and reaches almost a maximum, it reaches maximum value corresponding to the I critical the current density corresponding to I critical, and then if I further increase the anodic polarization I can reach to the passive range and that time my anodic current density would be equal to the passive current density, so the current density in the passive zone for in case of active passive metal is a very, very low value so I can get a very low corrosion rate, but in order to have almost, have this position in a very, very stable passive range then I increase it further so I reach here, but IA doesn't change still IA = IP but it reaches to a very passive region very, very stable passive region so I don't have any problem of getting, into getting the system into the active region.

Now if I put the value, now at this point my I critical is almost 10 to the power 3, 10 to the power 4, 10 to the power 5, so I critical is corresponding to 10 to the power 5, so that time its I applied corresponding to critical, then my value would be corresponding to 10 to the power 5, - 10 to the power - 2 milliampere per centimeter square, so it's a huge current. Now if I go there what could be my current density? Applied current density I need to send this value corresponding to 1, and this value corresponds to 10 to the power – 3, so at this point my I applied let's say I put P that means the I applied in the passive zone, this is my situation, let say corresponds to EP would be equal to, this is 1, and this is 10 to the power – 3, so 1 - 10 to the power - 3 milliampere per centimeter square which is almost equal to 1 milliampere per centimeter square, so that means it's a very, very small current density.

Now you know if I can keep the potential at this point for this active passive metal which is M, I need to send a very small current but still I will come across the corrosion current density of the order of 1 milliampere per centimeter square, but now this much current density I can achieve by cathodic polarization also, so if I achieve that cathodic polarization the same current density, this much current density I need to sorry, if I need to, this is my current density, if I go towards, if I go cathodically, if I protect this material cathodically then my current density, the same current density level if I would like to achieve so I need to go up to this point, so the negative polarization I have to give of this value that time I can experience that my current density corresponding to this much current density and this is also IA at this point, so what would be the applied current that is needed for cathodic polarization, this is I applied if I go for cathodic protection in case of active passive metal in order to get the same level of corrosion current density, so that time my value would be let's say this is almost close to 10 to the power 4, so if I go on the other side I'll see that my I applied would be equal to 10 to the power, this is that time I applied would be different notation because IC is more, IA is less and in this case IA is less, IC is less, IA is more, so that's what IC, this is IA or – IC, but in this case it would be IC - IA.

So in this case my required current density that is to be sent in order to get the same level of corrosion density, corrosion current density so that value would be 10 to the power 4, this is almost close to 4, that's what I'm taking 4, so 10 to the power 4 – 1, which is milliampere per centimeter square. Now you see the difference in values, these two values, in one case I need to supply only 1 milliampere per centimeter square in order to get the protection anodically and that time my current density corresponding to the corrosion rate, that is only 1 milliampere per centimeter square, but reverse case when we go for cathodic protection in order to get the same level of current density for the protection that time my applied current would be 9999 milliampere per centimeter square, which is a very, very large current. And the very, very large current means we need to spend a lot of money, so in case of active passive metal it is always advisable to go for anodic protection rather going for cathodic protection to get the same level of corrosion protection, so this is one advantage over cathodic protection in case of active passive metal, and that is also proven with respect to some numerical values.

Now the question is what are the cases we should go for? Now this cathodic and question is one is what are the cases why you should go for, and second is how would we increase the potential of a particular structure which is to be protected. Now if we see the experimental arrangement the way we should increase the potential of the metal object which is to be protected anodically that system is shown here, let say this is my tank, steel tank which is to be protected and this steel tank contains H2SO4 and we should have a potential stat, potential stat, now this is to be connected to, it is to be made anode that means this is to be connected to the positive terminal and we have one reference electrode and one counter electrode, this is my reference R means reference, this is my counter or auxiliary electrode, now we maintain a particular potential between this structure and the counter or reference electrode and that potential will keep on increasing and take the potential of this steel object or steel tank to this level, so this is a sort of experimental arrangement and this reference electrode will measure the potential difference between the counter and the steel object, so this is the experimental arrangement in order to increase the potential of the metal object which is to be protected anodically.

Now in case of the first condition what are the case, what are the situations, where we should go for anodic protection? One is of course the metal should be passive and it should be highly passivating metal. Now for a weak system let's say copper, let's say copper that case it cannot be a very suitable method generally we go for chromium, we go for titanium, this system we should go for this anodic polarization and of course during anodic protection we need this sort of arrangement and we are and, this sort of arrangement always involves a lot of money so that initially the establishment cost is very high, cost is very high but once we establish it and then take this to this level we will, that money that need to be spent would be very, very small.

Second thing is this method is to be applied in case of highly corrosive medium, so that is another part because it involves lot of money so we need to see that the metal object is to be protected completely by anodic protection, not completely means what I mean to say that in case of highly corrosive medium we should need to see that the metal object is protected to a considerable extent, and the advantage of this anodic polarization method is, it can have a same very low level of protection, a very low level of current density corresponding to the corrosion current density so we have a very small corrosion rate but the applied current would be very, very small, this is a very, very basis, the major advantage over the cathodic protection in case of active passive metal. So this is about the corrosion protection by electrochemical means, that means one is cathodic protection, one is anodic protection, in case of cathodic protection we have two ways, one is sacrificial anode, another one is impressed current cathodic protection and the other way around is the anodic protection, in case of cathodic protection we take the potential towards the negative side from the free corrosion potential and in case of anodic protection we take the potential towards the positive side.

Now once we see this let us get into another subject which is the different forms of corrosion, before I go to the forms of corrosion, let me again emphasize on the advantage of anodic protection or cathodic protection, one is, it can be used in a severe corrosive environment, severe corrosive environment or extremely corrosive environment. Now second case is the corrosion rate can be monitored all the time, can be monitored all the time, why? Because here we see that the rate of corrosion, the corrosion rate is proportional to the I applied, that's what we have seen the numerically.

Now third is very low current is required, very low current is required to maintain a very low corrosion rate precise control can be employed, precise control. Fifth is excellent current distribution, excellent current distribution that is possible in case of anodic protection. Now application and there are few disadvantages, one is of course this is costly, this is sort of advantage level and disadvantage, disadvantage, one is definitely costly. And second case if the metal is not highly passive this will not work fine and there is no protection over the water line, on top of the water line so if this is the water line on top of that water line, this is water line, on top of that if the metal object is there so this method will not be, will not give any protection. Third is non-conducting electrolyte, it will not work, it will not work and it cannot work for different metal in context, if different metals are in context that means in case of galvanic coupling this method will not be very suitable method, that case it cannot be applicable.

Now application, one is paper industry, this is application part, paper industry, then phosphoric acid plant, and in ammonia fertilizer plants for carbon steel, so there we can use this method. Now this is about anodic protection by electrochemical means and there are cathodic protections also, so by electrochemical means we can get rid of, we can control the corrosion rate to a great extent and we can have different level of protection at different metals we should choose a particular process.

Now coming to the forms of corrosion, this is about forms of corrosion, now in the forms of corrosion first letters have a different segment of different forms of corrosion and this is mainly based on the appearance on the metal surface, this is based on appearance, and we have a major, 8 major forms of corrosion. One is uniform, uniform corrosion let's say a metal is exposed to a corrosive, let's say about normal metal plate or iron plate is exposed to atmosphere or mild steel plate, that time after maybe after a year if we check the corrosion on top of the mild steel plate you will see that long top of the mild steel plate everywhere you have a red rust, and if we see how far it has gone inside, you will see more or less over the entire surface it is almost same level, so if this is the level of, this is the fresh metal object which is exposed to a medium, corrosive medium and after some time we can see that the corrosion is happening and after corrosion we will see that from all the sides we have almost similar level of corrosion attack and that has, and this part is lost due to corrosion reaction. So after some time we'll see that the all the sections the corrosion attack is uniformed, so this is an example of uniform corrosion and example is particularly the metal object or the iron object, mild steel object or structure which is exposed to environment, normal atmosphere.

Second is galvanic corrosion, galvanic corrosion in case of galvanic corrosion we have to have two metal contacts and one metal should be active, the another metal should be passive or sorry, active and one metal should be noble. So let's say two metal contacts, this is my one metal, this is A, this is B, and if B is noble and A is active in the galvanic series, in that particular corrosive medium then the active metal will corrode gradually and the noble metal will remain intact, so this is two metal contact corrosion or galvanic corrosion, here galvanic cell is formed between the noble and active parts of the structure and the active side is getting corroded and the corrosion would be more close to the, closest to the noble metal side and we'll discuss in detail on this galvanic corrosion.

Now third one is we have crevice corrosion, now crevice corrosion let's say I have a metal object and that metal object is connected to another fin, this is a fin, or let's say this is a rubber gasket which is on top of this metal object, now we see that there is a crevice between this nonmetallic object and metallic object, this is metal and let's say this is rubber, and let's say this is a rubber gasket. So now since we have a very small opening and which is a crevice and inside that crevice we can have a severe localized attack, and the severe localized attack can be such that this metal object will be corroded close to that crevice part and the rest of the part will remain intact, so this is called crevice corrosion, which is happening near the crevice section of a metal structure, this also can happen let's say I have a water tank and which is made of steel, now here also we can have two crevice or four crevice because since if we consider this is to be a rectangular shaped water tank, so I can have four crevice part, this is one part, this is one, this corner is crevice, this corner is crevice, this is another, this is another, all the four corners we can have severe localized corrosion around that four crevice part, this is another example of crevice corrosion. And crevice corrosion means, the corrosion happening near the crevice join now then we can have pitting, pitting corrosion. And pitting corrosion let say this is my metal object and we can have either a sallow pit, we can have a very, very narrow deep pit, or we can have a balloon separate bit like this, there are several appearance of pits and this pits are also very, very localized attack, you see in case of uniform attack all throughout these sections we have attacks or corrosion of this particular metal object, but in this case you see the outer surface before and after pitting formation has not changed much rather there will be very, very small change around this surface, all the corrosion will be concentrating on this pitting part so these are pits, these are pits and this is an example of pitting corrosion, the appearance how the appearance would be in case of pitting corrosion.

Then we have intergranular corrosion, intergranular corrosion as the name suggests that means between the grains, so if we have a metal structure, metal body and the metal body is generally polycrystalline, general polycrystalline and each are individual grains, individual grain and two grains are separated by a grain boundary. Now if we have intergranular attack and the attack will be on the grain part, on the grain boundary along the grain boundary, so like this, if we have intergranular attack so the solution or the corrosive will attack only the grain boundary part, the grain body will not get affected much. So here is one intergranular attack, this part also can get attack, okay, like that the corrosion will happen into the metal object along the grain boundary that's what it is called intergranular corrosion, this happens in case of 18:8 stainless steel and if that 18:8 stainless steel is sensitized we will talk about that later when we discuss this intergranular corrosion in greater detail.

Then we have selective leaching or Dealloying, selective leaching or dealloying this happens, this is a very, very common problem in case of brass or 70:30 brass, 70% copper and 30% zinc. In that case if we have a brass material and if we expose it to let's say some mildly acidic solution we will see that some part, this part will be enriched in copper, copper enriched, and the copper concentration in this part can go to even 90% initially everywhere the concentration was 70% with copper 30% with zinc, but due to this selective leaching or selective dissolution of zinc in this portion the copper concentration increases to say 90% from 70%, this is called selective leaching or we call it dealloying since the alloy zinc is coming out or zinc is coming out from the substitutional solid, solid solution position substitutional position, so this is an example of selective leaching or dealloying.

So we have 6, we have seen 6 different forms of corrosion depending on the appearance. Now the seventh one is erosion corrosion, erosion corrosion. And in the erosion corrosion we have corrosion as well as a sort of wear nature, so wear + corrosion, these two are combined in this erosion corrosion. So let's say we have a pipeline and the pipeline, through the pipeline water is flowing and let say the water contains lot of dirt particle, dirt particles so when it, let's say this is a sharp bent when it goes and take a change in direction that time in this part there would be a severe interaction between dirt and this surface and that dirt would have a sort of wear action and this wear action as well as there is electrolyte, so corrosion is also taking place simultaneously, so then we can have a situation and that is called erosion corrosion.

And this erosion corrosion we see that there is an effect of pressure, pressure or the dirt particle is moving and impinging on the opposing surface so that impaired this erosion corrosion that impingement effect can also arise due to fretting effect or it can arrive if let's say there is a reduction in pressure, water pressure or then there could be a formation of bubbles and if we increase the pressure of that water the bubble will collapse, and during this bubble formation low pressure and high pressure creation the bubble will form and then bubble will again collapse and during this collapse phenomena or collapse process huge amount of pressure that can be inserted on the metal surface, so then we have a corrosion effect which is called cavitation corrosion, so it can have two variation, one is cavitation corrosion, another one is fretting corrosion.

So cavitation let's say, I have a metal surface, on that surface a bubble is formed, now if the bubble collapse, the next stage if it collapse, bubble is collapsing, so when it collapses that time it leads to a huge pressure, it gives a huge pressure on this metal zone where this bubble is collapsing and this huge pressure can lead to a local breaking of passive film if they are ease in a passive film or if it is not having any passive nature, if it is a normal metal which is having no passive layer so there it can locally deform this material, so if there is a deformation then this can act as anode, so corrosion will happen here, and if it is a passivating metal then the passive layer will be broken here, so these part will be exposed to the fresh solution, so again the oxide layer will form or passive layer will form, by that time there is a little bit metal loss in this zone. So we'll discuss later also, but this is the phenomena which is happening due to this bubble formation and bubble collapse, and leading to the corrosion of that particular zone.

Now fretting attack can happen when let's say this is a metal object and on top of that another small metal object and this two metal object is under load, compressive load and if there is a very, very small relative movement between this lower part and upper part, so around this region there is the possibility of corrosion and that corrosion effect is called fretting corrosion. And the fretting corrosion we can experience in case of rails, let's say this is the rail which is, this is the rail and near that connection of fish plate, so the fish plate is connected, now when train is moving the line is expanding, so that expansion process will lead to a relative movement between this fish plate and the line, and when it goes, when the train goes that time this made, this line will again come back to its original shape, so there could be again another relative movement and all the time this fish plate and the line is under compressive pressure, so that time near this zone we have corrosion and this corrosion is called fretting corrosion and time to time this fish plate needs to be tightened and that's what people do, the line checker he goes and tightens this fish plate because constantly there is a rubbing action and the fretting action and that fretting action loosens this fish plate, so this is another example of fretting corrosion.

Now the eighth one is, stress corrosion effect, the stress corrosion the name suggests that there would be corrosion effect as well as stress effect and this stress is nothing but the tensile stress or the tensile component, here also we see that there is a stress but this is under compressive load and that time the relative motion is giving rise to fretting corrosion, but the stress corrosion primarily the stress means this is a tensile stress, and stress corrosion always we should see that because of stress the corrosion accelerates or it could be another way, other way around, there is a stress and corrosion is happening and that stress will lead to premature failure of the component. So the corrosion or the damage effect, the final damage would be combination of stress and corrosion but the initiation of that damage could be due to corrosion or due to stress, but both should combine to give lead to for the final catastrophic failure in case of stress corrosion effect, it can have different sections segments, one is stress corrosion cracking, stress corrosion cracking, which is informed short-form we call it SCC. We can have corrosion fatigue corrosion, corrosion fatigue and in case of stress corrosion cracking the stress component is a statics tensile stress, but in case of corrosion fatigue the stress component is alternating and this happens if we have a corrosion phenomena in a component which is under fatigue load. Now there could be another effect that is called hydrogen embrittlement, hydrogen embrittlement, so in case of hydrogen embrittlement there are possibility, for example on a metal surface if we see that the gradually the hydrogen reaction is happening and these hydrogen can get combined with some of the elements, for example zirconium hydride forming elements and those hydrides will form let's say there is a small crack and in this zone this reaction is happening and these atomic hydrogen will be adsorbed and finally it will react with hydride forming elements. And the hydrides will be forming around this zone and those hydrides are very brittle in nature, so since this metal object is under tensile load and the brittle phase is forming so immediately this crack will grow to this part.

So hydrogen evolution or hydrogen formation, then hydride formation, and then this brittle hydride will lead to embrittlement around this zone and due to the stress component tensile stress component this will be broken, so this is the example, this is an example of hydrogen embrittlement, so the corrosion, stress corrosion can also happen due to hydrogen embrittlement, corrosion fatigue it happens when let say there is the stress component which is alternating, okay and that time a small crack is forming due to corrosion and that crack will gradually grow and finally it will lead to a catastrophic failure. And stress corrosion effect that time this is under constant tensile stress and that tensile stress should be below yield stress so that means if we don't have corrosion it will not have any yielding, but since we have corrosion that and also we have a stress component which is tensile in nature we can have corrosion effect or we can have catastrophic failure.

Now for example this process can be combined with the intergranular corrosion let's say a sensitized stainless steel and that steel is under tensile load then the stress corrosion cracking can happen in case of sensitized stainless steel, why? Because in case of sensitized stainless steel we have seen that the corrosion is happening, in case of intergranular corrosion along the grain boundary, along the grain boundary and if it is under tensile load, so this part is weak part, there is no bonding so the metal, will be the metal object will be separated along this grain boundary regions and we can have a fracture surface which is called intergranular fracture surface. Intergranular fracture and you can see a very nice faceted structure and it will look like a grain has been pulled apart from another grain, so this is stress corrosion cracking.

So we have eight forms of corrosion and those corrosion are categorized on the basis of appearance but mind it all the forms of corrosion are interrelated, so sometimes in case of practical situation it would be very difficult to say that this is, this form of corrosion rather we have to combine most of the forms of corrosion and then say that finally come to the conclusion that these are the effects which would lead to, which has led to this problem, so these are the forms of corrosion.

Now the point is there are different effects which would lead to different forms of corrosion, what are those effects or what are those factors, now if we come to the factors of, factors deciding corrosion there could be different form different factors, one is let's say time, time is definitely factor more would be the exposure, more would be the corrosion, second is design, design of the component is a major factor. For example we have seen that how we have erosion corrosion a liquid is flowing into the, through the pipeline and that liquid contains lot of dirt particle and now when it goes like this that time those dirt particle are impinging on the surface, so finally if we have, this is my pipe thickness, this is my pipe thickness, so gradually this part would be corroded. So finally you will see that this part is having a leak, the leakage happens due to this cavitation this erosion corrosion because of the impingement of the dirt particle because the movement of this fluid, very fluid so here we have a failure leakage. Now this particular situation can be improved since there is almost ninety degree turn, now this particular process can be improved if we make design like this, instead of making a sharp turn if we have a smooth bent region, then we will see that there is a less chance of having a turbulence in this zone and then the liquid is gradually changing its direction and the impingement effect will be there but the impingement the severity of the impingement effect would be very less around this zone, so this can function for a longer duration, and that's what you will see that most of the cases the pipeline fitting, the fitted part you see one pipeline is there, another pipeline is taking a turn that time you have to have a bend or connector that connector is always having a smooth bend, so this is a design factor which can improve the corrosion, crevice corrosion process or improve the functionality of the particular structure against corrosion, so design is definitely a factor, but these are, now third factor since we are using this corrosion effect would be always considered, generally considered for metals and alloys, so we need to see what is the, what is the metallurgy of metals and alloys?

See the metallurgy it has a different subsections, this is important factor, one of course is in case of metallurgy if you see the metallurgy head there could be different, different sections, one is of course the purity or composition, purity or composition, purity of the metal or the composition of the metal that is a deciding factor, for example the composition let's say the stainless steel 18:8 stainless steel, austenitic stainless steel with the carbon content about 0.08% now that case this 18:8 means 18% chromium, 8% nickel and that case if we reduce the carbon content to a level of 0.02 or 0.03 weight percent we can reduce the sensitization tendency of that stainless steel, we'll discuss later. So the composition is important factor, the purity how would this affect, for example in case of commercially pure metals that time the impurity level is generally of the order of 0.1% or 0.05% something like that, now as we improve the purity the corrosion resistance improves. For example if we have a commercial pure aluminum and if we have pure aluminum, the pure aluminum will always be very good corrosion resistant compared to the commercially pure aluminum, that's what the pure aluminum if we have a component with pure commercially pure aluminum we generally have a clad of very pure aluminum on to, this is pure aluminum and this is commercially pure aluminum, so the body would be the commercially pure aluminum, but the surface would be pure aluminum, so in order to give a very good corrosion performance or the corrosion resistance of this entire structure, so the purity of course is an important issue.

Now then it comes the crystal defects, crystal defects this is an important issue, crystal defects there are four kinds of defects, one is defects one is a vacancy defect or substitutional atom so this is falling under point defect, then we can have line defect or dislocations, then we have surface defects and the surface defects, one is any surface of a metal or alloys is a defect, because that surface the metal bones are broken and the broken metal bonds are creating positive energy or contributing a positive energy we call it surface energy, so any surface is a surface defect or we can have grain boundary, grain boundary that is another surface defect, we can have stacking fault those are the surface defects then we can have volume defects, the volume defects, volume defects generally it contains voids, voids or porosity or inclusion, inclusions, those are volume defects. Now these defects nature of the particular metal or alloy can significantly affect the corrosion behavior of that metal. Let's say a particular metal the metal surface it is etched, and we see generally come across etch bits, those etch bits are nothing but the dislocation which is perforating or ending at the metal surface, this is let's say the surface of the metal which is etched and this is another dislocation which is coming and ending on the surface, then if we expose it to chemicals then this part which is exposed that dislocation which is ended on the surface that section will have higher tendency to get attacked, by the chemicals and that attack is a electrochemical nature and why it is getting attacked because the dislocation core is of high energy and the surrounding part is of low energy, so the high energy part will behave as anode, the low energy part will behave as cathode, so this part will be etched severely and there would be a small pit formation, and this is a very nice information if we measure the number of etch bits we can determine what is the dislocation density of a particular metal.

So we see that depending on the defect structure we can have a difference in corrosion behavior, another example is another sub effect would be if we have those, we know these defects are there in the material, now the material all is discussed then it is processed mechanical processing is done on those metals in order to improve its mechanical properties, in order to improves its different properties, mechanical, chemical all those properties by changing the micro structures, okay, so during this processing, secondary processing it is cast and then secondary processing means it is rolled or forge or something like that, during that process we will increase the generally we increase the number of defects, dislocation densities are increased, so if we increase the dislocation density that time the energy of the overall system increases, because more would be the dislocation, more would be the overall energy of the system, so if we have a cold work structure and if we have anneal structure where we have a very small dislocation density compared to the cold work structure we'll always come across there's a cold work structure for the particular metal will have a higher corrosion tendency than the anneal structure, so the defect structure is important.

Then we have grain structure, grain structure so most of the situations we have a particular metal structure or metal alloy structure which are poly crystalline in nature. Polycrystalline means poly means many, and crystal that means many crystals, so if we have a particular section if we see under microscope we will see that there are various number of grains and each grain is a separate crystal and those grains are separated by a grain boundary, so during formation generally this small tiny crystal forms during nucleation and that crystal grows, and grows gradually and let's say we have a melt, a small grain has small nuclei has formed and there is one more nuclei and this is a particular, this is a small crystal, and this crystal is gradually growing, gradually growing and finally there is impingement so when impingement happens like this, like this, so each section is a small, small grains, small nuclei and those nuclei are nucleus, those nuclei were growing and finally they were impinged and it takes the shape like this, so this is a poly crystalline structure.

Now in case of polycrystalline structure we can have the same material, same length scale and length scale means I would like to say later, let's say this is 100 micrometer, so in this structure this point if we put it so we will see that this is the level of 100 micrometer length scale so each grain if we see this it's almost 120 or 130 micron grain. Now the same material we can do some processing, secondary processing we can find a very, very small grains. Let's say I just draw this much and here also the length scale is 100 micrometer, so now see the same metal, this is A, this is A, but here the grains are bigger, here the grains are smaller, fine. Now and also per unit area if you consider there will be more number of grains here and less number of grains here, okay, so unit area let's say this is my unit area and here also this is my unit area, here we see 1, 2, 3, 4, four grains, there are four grain parts, but here if you see unit grain 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 13 grains, so that means we are increasing the number of grains per unit area, at the same time we are also increasing the overall grain boundary area, here see this much is the grain boundary, this much is the grain boundary, and this much is the grain boundary, so if we add all the grain boundary area since this is a surface defects, see if we add all the grain boundary areas in this case the grain boundary area would be more compared to this and we have already seen the grain boundary regions are susceptible to corrosion and if a material has a more grain boundary area it will have more corrosion. So the fine grain structure will generally have higher corrosion rate, so grain structure is also important and this is, these grain structure we can vary and this is falling under the metallurgical factors.

Now one classical example is let say we roll a particular structure, this is rolled, and this is two rolls and this material has been fade in and due to rolling, due to rolling this material cross-section is decreasing, fine, so we have, sorry not cross-section, it’s the basically thickness is decreasing and this is my rolling direction we call it RD, this is LT we call it long transverse, RD means rolling direction, this is long transverse and this is called ST or short transverse. Now when I do rolling the grain boundary, grain structure is having a particular pattern it will always try to arrange along the rolling direction, so and also there would be this grain art elongated due to this rolling action, due to this rolling action, and now if you see this all the grains and these grains are squeezed and also there would be this sharing action so along that LT direction, the grain structure would be like this, grain structure would be like this. Now if we see the structure from this direction, we'll see that this section it will be very, very fine grains basically all the grains are basically exposing, basically you have cut a section like this along the short transverse direction, so you will see this all those elongated grains are basically chopped along these sides.

Now if you compare these three sections you see this section as higher amount of grain boundary area, since this section has higher amount of grain boundary areas so the short transverse direction that plane always we have extra corrosion compared to the other sections and this section will have a very sharp small very, very compared to this it will have less corrosion rate since the grains are bigger, but the grain boundary area would be less compared to this, so this is a classic example what happens in different directions long transverse, short transverse and rolling, so this is the effect of grain structure.

Now then we have a deformation, deformation the example is given here if we deform we can modify the defect structure, we can modify the grain structure, fine, so defending on the modification that is going to happen due to deformation the corrosion property can change and you see that crystal defect, crystal structure, grain structure, and deformation, crystal defect, grain structure, and deformation all are interrelated, at the same time the purity and composition also can affect this deformation behavior, so we see that metallurgical related problem factors are very important and depending on the nature of the defect grain structure deformation and purity we can come across different appearances and there could be a possibility of having intergranular corrosion, there could be a possibility of having galvanic corrosion, those are the factor appearances we can get out of this factor, okay. So we will have another effect or the another factor that will decide the forms of corrosion or the corrosion that is environmental related.

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