

Corrosion, Environmental Degradation and Surface Engineering

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Lecture – 19

An overview of testing methods

Hello and welcome to the sixteenth lecture, of course, on corrosion, environmental degradation, and surface engineering. The topic of this lecture is an overview of testing methods. It has been shown that testing methods. The first question comes: do I really require testing because nowadays everybody is talking about digitization and computer programs? So, answers are written on the first slide itself, which says that many times we require structural integrity as well as functional behavior, which is also important. Now we have many components; it is not one or two components. So, that is why it is a diverse component and system.

Now, when we want some definite performance from a system or components, they need to be evaluated. We can do a lot of simulation, but finally, they need to be tested, and many times we cannot do a good simulation without inputs, or some inputs, and then we can develop some sort of correlation. We require three parameters, and we can drive ten parameters out of that. And so, it is a perfect combination of the software and hardware that are both required, and we are trying to emphasize that because we require hardware, we require data, and we require testing methods. So, that is why the first line of the point says the structural integrity and functional behavior of the diverse components and system must be evaluated by a critical engineering test. We have many ASTM standards also available. So, that is why critical engineering tests to ensure safety, as I mentioned in my previous lectures, are one of the most important issues, and wherever people are really operating the equipment, their safety is important.

And if there is some sort of contamination, pollution, or damage, that will really affect society. We have covered a couple of case studies indicating that there is a direct relationship between the systems and the human community, and if there is some damage to any one of the equipment, then naturally, society is also affected by that. So, if safety is important, then we want some sort of performance, and then we really require relying on the performance. So, that is why dependability and performance are important parameters for us as well. So, the testing is important from that point of view. Now, how do we really do the testing, and what is really essentially required? We say many times we need to subject the models; we are using the word models not necessary; we really require actual equipment.

We can make some sort of scale-down model or some representation of that equipment, and then those models need to be loaded because most of the time the mechanical units need to bear the loads. So, there is a need to be loaded or a series of loaded; it can also be a kind of variation in the loads. So, that can be done, and then we often check the flexibility, stiffness, and other related parameters as well as the strength of those parameters. So, we really required the properties because in the software we really required data, and those data will come from this test. So, that we can develop new and newer method, we can develop a newer and newer material, newer and newer technologies unless we have this data, we will not be able to develop new and newer methods, newer and newer materials, and newer and newer technologies.

So, that is why it was included, and then another consideration is durability, as I mentioned earlier. We need to assess how well it can withstand different types of loads. Initially, I talked about a single load or a series of loads, but we must also consider cyclic loading. In one of my lectures, I clearly stated that almost every system is subjected to cyclic loading. We do not have any fixed loading as such variation will be there. Now, how much

variation that can be decided, what will be the standard deviation about the mean value and then we can think, but more or less all the systems are subjected to dynamic load. As I mentioned that because of the wear out of the material dimensions will change, clearance will change, contact conditions will change again that will bring some sort of dynamic loads. So, if someone claims that cyclic loads are not present, that is incorrect. Cyclic loads will occur even in rolling element bearings. When a constant load is applied, the rolling elements continuously rotate, causing them to be repeatedly loaded and unloaded.

So, it will be subjected to a dynamic load. The same thing happens with gear; the same thing happens wherever there is a mashing or some sort of loading and unloading mechanism, directly or indirectly. So, that is why we really required fatigue testing for this duration, we really needed fatigue testing. So, for this purpose, we did require a static test, a fatigue test, and then a static test, again if we wanted some sort of permutation combination. We can give a minimum value or a maximum value to figure out whatever the results are. Another important thing is a wind tunnel, because we know wind tunnels are very very important particularly for checking aerodynamic behavior, and when buildings are now getting taller and taller, we really need to look at what the aerodynamic load will be on those buildings. Bridges are also then subjected to aerodynamic loads, and moreover, other aeroplanes and aircraft are important, as are the elements that have been utilized for this and the systems that are very important.

So, we really required this kind of test. So, we can say the first is important and the second is important. The third one is a realistic situation. Suppose we have done some sort of test and we do it in a lab, but what will happen to the actual case when the system is really running? So, but that is why we really also required some performance and realistic setting, and then we often utilize some sort of vibration analysis, deflection, or strain analysis thermal performance. I mentioned about titanic failure, and I mentioned that the water tightness was one of the major issues, and then the water got in, was locked into the compartment, and flooding happened also.

So, those things are important. When we think about power losses, energy efficiency will turn out to be very important. So, these are the realistic cases, or maybe we don't really do only the lab test, but we do the performance test on the actual systems. So, those are important, and most of the tests can also be conducted at the initial level before really launching a complete product or a brief product. This can also be done in the lab. In that situation, we only need to scale down the models, and when we scale down the models naturally, we will lose something, but we will gain another lot, and then we can understand that we can continuously improve. That is why we have written here that based on the results of the test, whatever we are getting, we can make the necessary adjustments and modifications.

When we develop any new technology or material, we naturally need to perform a number of experiments, and even though we do a lot of simulation, the simulation itself requires data. Those data require some sort of test, which can be performed. I can utilize the second one, which is lab test-related, too, but when we do this kind of thing, we will find some sort of lack of understanding. We need to build on that; we need to compile new findings and continuously improve the performance. So, that is why we can make the necessary adjustments and modifications to the structure to guarantee efficacy and safety. So, we really require tests to achieve this one. Now there is some other kind of thing called visual inspection. Generally, we go hard, and although it may be a very popular method, we do that kind of thing.

So, visual inspection is a kind of radiographic testing, and sometimes we do ultrasonic wave testing and some magnetic particle testing. These are some well-known non-destructive tests, and that is why non-destructive testing is playing a very important role, particularly for this course. We do have destructive testing, which may be in the following two or three slides. I will explain those things, but if there is a need to continuously improve, we should mostly look at the NDT performances. We need to evaluate continuously. So, so that we can take the necessary measures, another thing is that even though the system has been developed, it has been launched, but the requirements for maintenance will vary from one situation to another. In that case, we really required an NDT test,

and I will be explaining a few techniques on that that will be really required. It is important, and in the previous lecture, I explained that the major thing is the local defects.

We are not looking at the complete failure, even the initiation of the failure or may be the local defects. If we are able to identify repair or may be corrections will be much easier at that level; it will not cause a major casualty, but if we do not really look at those points, then a major casualty or major loss may happen. So, that is why the NDT plays a very important role to inspect, and then, with the correlation or whatever the science, we can develop a relation as to what kind of measures or, may be, what kind of maintenance strategy is required under the various situations or various conditions. Then this is an NDT, and I mentioned that we really required data for the simulation or modeling. We required a tensile for the data, compression, and banding-related hardness. So, these are the properties that will be required when we do the kind of performance test, or we really require a simulated performance test. We do some modeling, and then we try to simulate the actual case. These data will be required not only for the metals but may also be required for concrete, wood, or composite materials, with composite being a newer material. Many people are trying to replace other conventional materials with composite materials, which naturally have more and more properties and may be used in various situations because composite properties are very sensitive to other shapes and sizes, and then ingredients really require more and more results or data to really give good results from that.

So, what I'm trying to convey is that testing methods are important, which is why this lecture is essential for this course. We've already discussed corrosion testing and reviewed several standards for it. To summarize, corrosion testing involves evaluating materials under controlled conditions. We aren't considering uncontrolled conditions when we specify HCL concentrations, sulfuric acid percentages, or citric acid percentages. These are all controlled conditions. Similarly, when we discuss temperatures, we might vary them up to 100°C or between 100°C and 200°C. These are controlled environments in which we aim to keep the system stable.

So, the corrosion of the material under controlled conditions can be determined, and then we can really relate to the life span of the material. We can develop models for that. So, this is important, and many times coating and corrosion production methods are also used to protect against different kinds of corrosive actions, like crevice corrosion, fatigue corrosion. One of the simplest ways to avoid this issue is to prevent excessive electronic transmission. You can introduce methods to achieve this, but these methods also need to be tested before implementation. So, that is why we need to cover corrosion testing from that point of view, and moreover, I also explain that whenever the corrosive condition comes, a failure mode is also changing; it is not that a failure mode remains the same because they are acting, or they may be assisting or existing failures. And then shifting from ductile failure to brittle failure, or, may be, high cycle failure to low cycle failure. So, there is a need to understand, and even if we have understood and then developed a product according to that, naturally, it has to be tested.

So, this is important, and then it really helps us to suggest what the corrosion mitigation strategies will be. These are important points, though we need to really look into them. Now another one: suppose I want to develop some product for the marine situation and marine environment, and in one of the earlier lectures I mentioned salt vapor or salt water. So, that kind of environment can be created in our lab itself. So, we can say here that by subjecting the test specimen, we have already explained something like stainless steel and different kinds of chromium and nickel. So that increase and so that increase the corrosion resistance, those need to be checked in the control environment, or where the artificial or synthetic sea water can be synthesized, that can be done.

And moreover, this is important whenever we think about the corrosive environment, or, may be, the marine environment, which is corrosive in nature and needs to be made properly and then follow ASTM standards. In our previous lecture, I discussed the necessity of adhering to ASTM standards when synthesizing seawater. Now, sometimes we really want to know if a specimen remains dipped in an acidic or corrosive condition, and that may be for some time, and then it may be for 5 hours, 10 hours, 50 hours, or 100 hours, and then how the life is going to change, how the strength is going to change, and what will be the resistance of that material. So those things can again really record corrosive testing to be done in this situation. The question comes: how do I really see the

impact of corrosive media. Sometimes we try to measure weight, and visual examination is another method we use. Mechanical properties are often significantly affected, such as endurance strength. For example, some steel has an endurance strength, meaning it can theoretically last more than 10^6 cycles indefinitely. However, this also changes, and there won't be any fixed limit. As the number of cycles or hours increases, the strength will continuously decrease.

So there is a change in a may be even whatever test we have done initially and then if we do a testing in a corrosive environment. Results may be different significantly, and then those results also may be time dependent on. So it is not that whatever we have tested today will remain constant for irrespective of time that will change, and then that can be evaluated for a number of days. One of the way is accelerated test that also can be done that way. So another one related to corrosion is a electrochemical measurement, which can really provide information on what the corrosion rate is and how fast the material is getting corroded. Another one is what will be the potential because of the of the different materials. In one of my lectures, I mentioned the different materials and gave their ranking based on their potential.

So what is the corrosion potential that can also be figured out using this kind of material, or even if the material is getting oxidized, getting chloride may be saying a sulphite, then what will be the change in their corrosion potential that can be checked using this measure? These considerations are important because we strive to improve materials continuously. When we apply nano coatings or micron coatings, we need to understand how these changes affect the product and its corrosion protection system. So that is why there are a couple of pieces of equipment; the potential denominator and dynamic scanning are one, and then we try to figure out the electrochemical impedance spectroscopy and polarization resistance. These are the instruments particularly suitable for the corrosion testing, and they are important in this situation. That's why we say these are useful in electrochemical testing methodologies.

So corrosion testing itself is a big domain, and as one of my earlier lectures said, the corrosion itself is a complete subject, and ASM has a complete one-handbook on corrosion, followed by the complete corrosion and the related testing as well. If you want to really do an accelerated test, I do not want to wait for the years that will pass. What will happen after 5 years? Actually, I need to mimic what will happen in 5 years, which may be in the next 5 days. So I have to come up with some sort of accelerated test. What is the purpose of an accelerated test? I can increase the load significantly, I can increase or decrease the concentration depending on the requirement of some chemicals, or maybe I can really enhance the temperature, like the ozone temperature, and the duration will clear instead of one equipment operating only 8 hours per day. I can really work continuously for 24 hours a day, and it may be for the same number of days continuously. I can determine the impact and how the material's history will affect the overall results. For instance, if I choose not to cool it in between or not to allow the material to relax, what will be the overall effect? This is why we say that accelerated tests are important and that different models need to be developed with careful consideration. Now we will be covering those aspects also, and then we say that we actually want to really mimic what will be the long-term exposure. Now there is some sort of light pole, and then we know that this needs to survive 15 years. I cannot really keep a light pole for 15 years and then keep measuring performance. I need to really finish, which may be in 30 days.

So I have to really simulate. I need to really mimic those conditions. Bring us those conditions, which may be to say increase a very high wind force in the wind force, or that gives results, or maybe I need to go at a much higher corrosion rate compared to what has been given, because if I increase the corrosion rate naturally, the time will increase and then decrease overall, and then you can complete the test, and instead of long-term, I can finish in the short term also. So these are the important aspects when we think about the corrosion testing. There is another, as I mentioned, high temperature in the corrosion itself, and when there is a high temperature, this reaction starts very at a higher level because of extra energy, and that may not be linearly correlated; these may be the kind of exponential reaction, or maybe the power relation, and then the sensitivity of these types of variables is significant. And in one of my earlier posts, I mentioned that by increasing the 100-degree centigrade temperature, it is quite possible that the fatigue life can be reduced to 50%. Therefore, to achieve 2000 cycles instead of 5000 cycles, I

need to raise the temperature. Based on this perspective, I can establish a clear correlation and implement it accordingly.

That is why there is a need to simulate or mimic the power plant exhaust system, and all we really require is testing in this case. In this case, the big company has its own R&D centers, and then they keep doing this kind of test, and from an academic point of view, at least initial knowledge is very important. We may not have complete knowledge, but we need to have knowledge that can be compiled and then proceed in a systematic manner. So that in the future, whenever we have a functioning company, we are exposed to this kind of environment. We can compile our knowledge in a slightly better manner, may get better results, or may have better data, and then we can improve the overall system with our own creativity and our own thinking, which may not be what people have thought of. That is how everybody is in science; everybody is an individual and can think in a in a slightly different manner. Naturally, as more and more people think about a common goal or may be say to improve the performance, day by day performance will improve. These are the tests that are important, and the and the data are important. We do not have to just believe whatever has been mentioned many times; we do not have to believe whatever has been mentioned many times. We need to prove ourselves because we know the situation has changed, the environment has changed, the temperature has changed, and the level of environmental pollution has changed. It and the level of environmental pollution has changed. It may be that around 20 years ago, the SO₂ level was not that high, the anode was not very high that much, or the particle debris was not that high, but the environment has changed. So, if we really want to get good performance from our systems even in this polluted environment, then that needs to be done, and we may also get improved performance compared to the previous one. Only then can we be competitive; otherwise, we will not be able to be competitive in the world.

In our earlier lecture, we discussed material testing, including the tensile test, which is essential from both a mechanical engineering and metallurgy perspective. The tensile test measures properties such as yield strain, ultimate tensile strength (UTS), and elongation. These properties help us understand how a material behaves, particularly in terms of crack initiation and propagation, as well as other fracture-related properties. For example, a material with more than 5% elongation is considered ductile, while less than 5% elongation indicates brittleness. By measuring elongation percentages (e.g., 8%, 10%, 11%), we can classify materials and derive other related properties.

In fatigue testing, we repeatedly load and unload the material to simulate real-world conditions. This can involve varying temperature, load, or stress to mimic potential damage to the material. Experiments like the creep test, which can run for months, are performed to understand how materials will behave over extended periods. But we can do an accelerated test with that, and then we can try to mimic that. Try to mimic a situation where we are getting a higher scale factor; we get a life x , but actual life will be $3x$, $5x$, or something like that. So, that is also possible, and we see that the fatigue life and ultimate tensile strength of material can be estimated mostly within this test, with the most correction factors that we will learn through the design. There are a number of correction factors. So, when we have ultimate tensile strength available and we want to find out the fatigue life, we multiply by the number of correction factors, and that is why it is important to really go through the design strategies. When we really do this, the data will come from this material testing. Another important parameter generally from a fracture point of view is fracture toughness. Even though in the wear testing or for the corrosion immediately we do not really require it, fracture toughness is one of the important properties that has been known for the materials, and then we classify or choose a material based on that.

So, the material toughness is also important and major thing is that what will be the materials ability to withstand the spread of the crack, that is important for us to understand. Another one we say that sometime we say what will be the critical stress which further to avoid or maybe to find out the threshold, that if the stress is more than that then possibility of the crack propagation will be more or maybe significant will be really countable. So, that needs to be also decided in this case. Another important aspect is fracture testing, which determines a material's resistance to crack formation. Although we often think of cracks as already present, they can be infinitesimally small and may not expand unless certain conditions are met. These conditions include specific material properties,

associated parameters, or stress levels. When stress reaches a certain threshold, these tiny cracks can accumulate and form noticeable cracks, from which crack propagation will begin. So, initiation of the crack what is generally used initiation of crack that means kind of material which is subjected to stress beyond that if the stress increases then the crack will continuously increase.

Otherwise, it may not be considered a crack, but rather a discontinuity in the material, similar to grain boundaries. We know grain boundaries exist and act as discontinuities. The question is whether they should be treated as cracks initially, or if stress concentration at the grain boundaries, due to excessive stress, deformation, geometry, or corrosion, causes them to become cracks. Those needs are important; we need to think from that point of view, and then overall, the impact test is also there to know whether the material can withstand the breaking or not. So, this is the final form, and in our course, we say we will be restricting ourselves to the only wear debris generation. We are not thinking of complete breakage of the part because that is a failure. We do not want that kind of failure, and then if wear debris generation, corrosion, or maybe chipping off of those wear debris that is coming out of the surface, If we are able to stimulate, if you are able to judge, if you are able to really think from that point of view, we can avoid complete failure or catastrophic failure, and then we can give well-in-advanced information. And that is why the NDT plays an important role. That means when we are making the product or system, that is the initial level, but how it will behave in real life, or maybe in working condition, those need to be tested, and necessary measures need to be accounted for or may be taken, as well as mitigation strategies that also need to be thought over to determine what kind of maintenance strategy needs to be applied to mitigate those kinds of failures that need to be thought over.

That is why engineers and material scientists use this kind of testing result to design structures, evaluate the safety of existing components, and develop new materials. If we know that some sort of manufacturing process is not correct and we need to improve that manufacturing process or some sort of heat treatment is not correct, we need to improve that heat treatment or maybe the mixing. When you are thinking of the composite material, you may think that some sort of ingredient or composite material is not appropriate or that the orientation is not giving the desirable results that can be found only when doing the testing. Without that, everything will be simulated, which will not yield fruitful results. So a perfect combination of testing and simulation or modeling is required to achieve overall better and better results and, as we say, better and better technology in the modern world. Now let us start with our lecture, and we are saying that there are testing methods. How do we classify this testing method? What are the criteria?

Now before going to that, I am just saying that I have to think about the fact that I need to make a team of nine; it can be a product, it can be a system, it can be like the various units. So, I am giving number 1, 2, 3, 4, 5, 6, 7, 8, 9, whatever units I think in any way. Now I need to test whether this unit is a fit for overall performance or not. I also need to test the second, and I also need to test the third, because when we select or choose, we need to have some sort of quantified parameter. So, that's why each unit is crucial; every individual unit plays a significant role, much like a cricket team composed of 11 players. Each of the 11 players needs to be selected carefully; I can't just focus on one as the best and neglect the others.

Every individual needs to be the best, every subsystem needs to be the best, and every component needs to be the best. In one component, there may be 6 properties, 10 properties, or 12 properties; those also need to be the best based on available resources. So, when we think of a team as a whole, we require overall performance, but each individual system, subsystem, component, or person may be the best; if they do the best, then only the team will be the best, no matter how much it will not be. So, I am just trying to say that component 1, component 2, component 3, and component 4 need to be the best again, and their interface also needs to be the best. So that is why we say assembly is important, and then these tests are required. So we required individual-level performance; we required assembly level performance.

So, if I think from that point of view, I can divide the category itself into an assembly point of view and a component point of view, while in the case of the testing method, whether it is destructive testing or non-

destructive testing, So some examples have been shown that this is a kind of destructive testing. We are showing here, and some sort of non-destructive testing has been shown in this case. So, we classify from a destructive and a non-destructive point of view. So, this is a meaning of destructive point of view that we really subject failure, we really damage specimen as such to find out what will be the major upper limit of that load, or may be speed or may be temperature, what will be the related component or subsystem that will fail. So, this is a word we use to describe the damage to material or to say that we should go ahead with this testing, which really gives a final, limited value; some may say the yield strength is this much. Naturally, I need to feel the component or fracture toughness. If it is this much, I need to really figure out how much energy has been lost.

So, this is demonstrated as something akin to a Charpy test. Sometimes, people describe it as developing a crack and then impacting it with a hammer, which is why the hammer is depicted here. We impact, and we try to figure out before the component fails in the two parts how much energy was absorbed. Therefore, this provides a measure of the component's resistance to failure. If energy has been given much lower, quite a possible component will not fail that much; may be the crack will initiate and then the growth to some extent, but then the life cycle will still be there. So, in this case, we try to figure out whether this is a distinctive test. I say detesting as such now coming to the NDT that kind of thing, here the completed assembly has been laid down, complete pipeline is there may be. There are inside the fluid may be some pressure or may be some velocity and there is some unit on top of that to figure out. Now we can try to figure out what the coating on a surface will be and whether it has been damaged or not.

So, coating testing can also be done using the NDT non-destructive test, and it may be that the DT is a destructive test. So, we can have a sensor, or a final may be in situ in a real-life situation. What is the performance? So, we really required an initial value that could be utilized for the software. We can also do a kind of final performance testing, which will give the results of whether the everything is under control or not, if there are some chances of failure or not. So, we can determine based on that. So, we can say the major classification will be something like destructive testing and non-destructive testing, and if I try to give a little bit of a classification in an appropriate manner, Destructive testing, in my opinion, entails putting a specimen or sample under a load or stress that may eventually cause it to fail or permanently deform.

Testing is done to learn more about what we are trying to achieve. So, testing is done to learn how materials behave, figure out their mechanical characteristics, and judge whether the material we are selecting is suitable for our application or not. So, this is a description of the test. Now, coming to non-destructive testing, or NDT, we say non-destructive testing refers to the collection of the matches. We are not necessary only one method it can be many methods. What we are trying to figure out is inspecting, assessing, and analyzing objects without inflicting any destruction. So, without really imparting any destruction to the specimen, instead of the word specimen, real component as such, because we generally do not make much specimen in NDT.

We say the NDT techniques are used to find out the flaws or inconsistency discontinuities in a system to ensure the performance and integrity of the subject. And in my earlier lecture, I mentioned that cracks, flaws, and discontinuities are the major culprits, or maybe if we are able to diagnose and figure out what is quite possible, the final failure can be avoided. We can take a number of corrective actions. We can reduce a load; we can reduce a temperature; or maybe we can do some sort of coating on a surface. So, when the flaws can be really reduced, or maybe we do a number of mitigation measures, that is why surface engineering will be dealt with in the final portion of this course. We will try to mitigate all those faults that we are getting or maybe are able to think of, and then we will come up with an overall reliable source or overall reliable solution. So, I can say non-destructive testing is required for quality assurance, maintenance, and safety checks in various sectors or various industries, the reason being that it allows material or maybe structures to be examined and evaluated while still in place.

In the case of destructive testing, we do take some sort of specimen and try to evaluate its performance. While in NDT, we can directly go to the site and figure out what is happening, like a power plant. I can do NDT on the power plant turbine blades, or maybe the turbine as such, which is running in the situation we can do NDT on

here. And then it is important to note that NDT tests are very important to minimize overall failures. However, in order to obtain the necessary data for our design purposes, we must first compile the necessary software, select the right materials, and choose the right coatings, all of which can only be obtained through destructive testing (DT), those are important too. Now I try to summarize whatever I mention in a slide form—we say destructive testing versus non-destructive testing—the techniques we are trying to compute.

So, either DT or destructive testing puts a test specimen through conditions in order to break or deform it. You do not get the same shape back materials, or maybe the sample you are using will be deformed or break as well. As you have seen in the UTM, we also break the pieces tensile stress. So what we are getting in this case are structural or mechanical qualities that are really required performance limits, as I mentioned about the yield strength UTM, other than the ultimate tensile strength, and another possibility of failure modes. How may shear failure be the tensile failure or maybe say brittle failure or ductile failure? We can really figure out from those, and of course we will develop a science on that. And then this can be learned through this sort of testing, and earlier the tensile testing compression in the testing. This is basically the many times we assume materials are even material, whatever the tensile strength that will be compressive strength, but in recent time it has been revealed. It does not happen that compressive strength is many times higher than tensile strength. We also need compressive testing to determine the maximum load a material or section can withstand before breaking into parts. Additionally, bending tests help assess flexibility and fracture resistance, correlating with impact testing such as the Charpy test, where the material is impacted instantaneously.

And the last one in this case has also been shown: surface hardness testing. What do we do? We try to figure out how much density we are able to prove, and then the punch makes in a surface or even the scratch. If you know, go for the microhardness, which is what the depth, or maybe width, of the scratch is and what kind of scratch we are able to really generate on the surface. So that gives us a surface hardness property, and that is very important, particularly from our point of view, when we say the wear failure is right. So, we say the evaluation is performed on a representative sample. So many times, people try to see DT; it is not really damaging the systems; it is just trying to take one sample and try to figure out the properties.

So the sample preparation and the failure should not be treated as demolition or destructive testing; that is what many people feel. That is why I am trying to say here that the testing is performed on the representative sample, and in my view, even if the representative sample is failing, it is still part of the destructive testing. Now coming to the non-destructive testing, we say NDT can say the material or systems of quality; in this case, I am using the board. It is not only the material testing; it also tries to figure out what the system qualities will be. It is trying to figure out flaws, defects, breakdowns, and some sort of discontinuity, or some anomaly, in that we say that which is available in the system.

However, all testing should be conducted without compromising the product's integrity or causing any damage. Non-destructive testing ensures that there is no harm to the material or system, preserving the product's utility. It is essential for assessing quality and integrity, identifying weaknesses in subsystems or components, and locating potential issues. This allows us to repair, rectify, or mitigate these weaknesses, ultimately improving the product.

So that is why we say NDT techniques permit inspection, monitoring, and quality control during manufacturing and while the product is in service. So, from that point of view, I find the NDT very important for us, and we should opt for the for the for the NDT if these are available. Now reason being that sometimes we say NDT has three words that are very useful for us. What are those three words? It saves money, it really provides good safety, and another thing is that it meets all applicable regulations. So, most of the NDT equipment is made in a manner that meets the regulation without damage or deformation. So that is why sometimes we will say that it saves money, it is a good safe one; there is no destruction, no damage, and then it also follows all rules and regulations.

So the person needs to really go through or read all the established, and that is why, many times, you will say that whoever is a NDT operator requires some sort of certification, whether they have cross-level 2 or cross-level 3 or

something like that. So, these are the important ones, and people need to really read and follow those regulations. If I were to truly categorize the testing method, So, as I say again, I am repeating the classification of testing methods. I have already briefed you on the distinctive testing means, properties, and failure characteristics of the test specimen. Again, I am using the word it is done on a specimen; it is not done on the actual system as such.

Then, during non-destructive testing, it really figures out the defects, quality, maintenance, and what the maintenance requirement is for us. Another thing that is more important is economics, and whatever the measures we are considering, whether they will be economically beneficial or not, and it really goes through the rules and regulations, and whoever is really operating entity equipment, they really follow them, so they go ahead with regulatory compliance as such. And then this also really helps us to understand minor to minor detail about the technique of the system or technology-related technology, and there is a possibility of continuous design and continuous technology improvements. In recent times, I believe that this type of technique is becoming increasingly innovative, and newer techniques will continue to emerge, providing us with a wealth of knowledge that will enable us to create ever-better products.

This is why we assert that the production process naturally requires both components. After all, the system is in a place where it plays an important role, and that is why the entity will be more important, but initially we really required a number of data points that we also required DT. So therefore, these two methods are essential for production, quality control, and safety assurance. not say only entities are the best, and I remove completely destitute testing. However, people are doing it, and they are trying to come up with a better and better method so that even all the properties that have been measured using destitute testing should be measured using the non-destructive technique. That will be very good, but it is still in the research phase, and we do not have a complete commit of those technologies or techniques. Which we can utilize, and then unless it comes in a widely used form, when we say useful form, it will remain a kind of research topic, but research people are doing, and then they are trying to convert the destitute technique to the non-destructive technique. So then more and more testing can be done, and more statistical analysis can be done, and then we can provide a better result instead of only making a few samples during a destitute test. We know this is a statistical method with the property that all are statistical. Naturally, we require many samples to be damaged to come up with the right results. However, destitute testing of the corrosion plays a major role in this case, and destitute testing of the corrosion is important, and we need to know about this. However, a number of people are doing simulations to try to replace the corrosion testing, but it will still take some time. Furthermore, in addition to mechanical tests like tensile strength, peel-off tests are necessary when applying coatings to surfaces to determine how effectively they can be removed. These include crush tests, compression tests, fracture tests, and impact tests like the Charpy test.

Those are the important properties required initially for the design of the product; that is one important one, and maybe even the test specimen is made. What will be the say and the resistance strength of a will be the life, what will be the cycle, and then, as a one of the case studies, I mentioned that an increase in temperature reduces the life significantly, but if you do this through the testing, it will really give more reliable results compared to only thinking from a modeling point of view or from a simulation point of view. Coming to non-destructive testing, it is a really recent topic, and many people are working on conventional non-destructive testing, as well as continuous research, in which the researchers are trying to find out newer and better techniques. So, what is the conventional technique we know as visual inspection? The visual inspection can be naked eyes with some sort of microscope, or maybe an optical microscope, or maybe other high magnification methods. Ultrasonic testing, radiographic testing, and magnetic particle testing are also what we will be explaining in the next few slides. We know the eddy current probs or eddy current test, thermographic test or maybe thermographic cameras also, and we also know the liquid penetration test and the caustic emission test. It is relatively new that the stress strain DIC testing is basically that we take an image and correlate and try to replace existing strain-based sensors. So here we are capturing the image, and then we are finding the relation or correlation. So that it is a completely non-destructive test, and we will be trying to figure out what will be the strength, what will be the stress, and what will be the elongation really without the specimen being subjected to that level to a high level.

However, these are the techniques that are really required, and this is an overall kind of overview. Initially, we will be covering this technique one by one in more detail or depth, and if I really look at what the purpose is, what are the main ways to classify, and why we are putting in the two classes. Destructive and non-destructive testing methods are typically categorized based on their objectives, whether they cause damage to samples, the type of samples prepared, and the information conveyed to those conducting the tests. These methods are applied across various applications.

So, these are some major ways that the classification, or maybe comparison, has been performed. That is why we said here that the destructive testing purpose is slightly different. We say we try to determine the mechanical properties and then set limits on them, and that is what I mentioned. In the case of non-destructive testing, the basic purpose is to find out what the irregularities and discontinuities are, and then, so that we can avoid a final failure, we can do better maintenance.

So this is very important from that point of view. I already mentioned that the destructive testing of the specimen that we are using will not be useful after that. So, we cannot repeat another test on that, while in the case of the NDT test, we can repeat a number of experiments on the same samples. We can really change the sensor's location, and then we keep checking the level. We can use the same units repeatedly, engaging the sensors for several hours at a time, to obtain a more sophisticated analysis. So here the samples are not damaged, or maybe the systems are not damaged at all, while in the case of destructive testing the systems are damaged. In non-destructive testing (NDT), there is no need for a specific test sample, allowing for in-situ or on-site analysis. In contrast, destructive testing cannot be conducted in situ; it requires extensive analysis and often involves scaling down from a representative model rather than using the actual model.

So if there is some sort of length that is going to affect or some sort of shape that is going to affect the strength, then whatever I get from a DT may not be correct. If the shape is changing and the material properties are changing, naturally I cannot use the DT research, or maybe instead of 5 mm, if I make 50 mm, the properties will change significantly. Again, I cannot change the destructive testing. That is why more and more research and more and more orientation are going for the NDT side so that we get results as such from the point of view. Now coming to information, this gives information related to the properties, which is really required initially for our simulation purposes, while information that gets conveyed from an NDT is really from the maintenance point of view, and then correct your mitigation strategy point of view. We say that it gives the presence, location, size, and severity of defects and irregularities in the material, so we can determine what the residual life of the system is. Whether it will survive for 5 years or 10 years if I change and apply a mitigation strategy, then what will happen as such? Application point of view: as I mentioned, this is required from a simulation point of view; it will be useful from a research point of view and material characterization point of view.

Another very important thing is that if the failure really happens, we need to figure out whether the property of the fracture surface remains the same or has been changed significantly. Therefore, we can effectively determine the underlying reason for the failure, such as the transformation of a ductile fracture into a brittle fracture, as demonstrated in the previous slide. So, when the fracture happens, we can figure it out and then try to correlate it. So, this is a failure when a component has failed, a system has failed, and after that, we are doing the testing on that. So, in this situation, we are not really making the initial sample the way we were making the initial sample. However, because the restrictive testing also has some sort of limitation on the specimen or size, we need to cut the material; whatever the big gear fails, we may chip off the gear teeth or whatever the fractured surface, and then we try to go ahead with the restrictive testing.

This primarily serves as a tool for quality control inspection and maintenance, an area that necessitates increased attention. So that we can think about overall surface engineering and come up with better and better results. If I try to write or maybe think in my way, we say that there is a distinction; we say that there is a significant difference as

such from a philosophical point of view. We say that the most notable distinction between DT and NDT is their respective strategies. How we are following, and finally, what is the outcome. The goal impact and information gained through the DT test are a bit different, or maybe sometimes we say vastly different, but they are different compared to NDT. So whatever information I am getting will be slightly different or maybe the same; some people say it is vastly different from NDT.

However, with the research, we are trying to bridge the gap, and we are going to keep moving on the NDT side as well. Another one is that we really required a DT, or the destructive testing of material, to discover various material limits. What will be the upper limit that NDT cannot give as such? NDT can tell whether the material is safe or not, it will tell how the program and the failure are progressing. While in the DT, we really co-hired the final failure.

We establish this as the upper limit, acknowledging it can vary with different conditions and environments, particularly in destructive testing (DT). In contrast, non-destructive testing (NDT) focuses on detecting defects, irregularities, and damage without destroying the sample or system to obtain properties. This approach supports improvements and maintenance efforts, aiding in determining residual life based on specific DT data.

As previously mentioned, DT can irreversibly harm specimens, rendering them unsuitable for reuse even after attempts to restore their shape. Conversely, NDT allows for risk-free inspections that can be repeated on the same sample, system, or component, making it ideal for onsite testing and inspections where uninterrupted operation, such as in a running boiler, is crucial. So, we can still do a testing or turbine is running still. We can do testing or power plant is still running we can do a testing, while there is some sort of over haul maintenance then we need to stop. Otherwise, NDT does not really interfere with any activity so that is why it is an important particularly on the onsite testing, and then try to give right results and the health of the system as such. So, we can say the NDT can be performed on actual material component on building eliminating the need of manufacturing any test samples. So these are the important for us. Thank you.