Corrosion, Environmental Degradation and Surface Engineering
Prof. Harish Hirani
Department of Mechanical Engineering
Indian Institute of Technology, Delhi

Lecture – 24
Selection of Non- Destructive Technique

Hello and welcome to the twenty-first lecture, of course, on corrosion, environmental degradation, and surface engineering. This lecture focuses on a selection of non-destructive techniques. Even though I'm focusing on Non-Destructive Testing (NDT) in this lecture, the selection procedure I'm about to describe is applicable to many other scenarios, such as choosing a material coating or selecting a tribometer for testing. The process remains the same across these different applications. However, I'm using NDT as an example because we've recently covered these techniques in the last three or four lectures. We discussed nine techniques in total: visual inspection, ultrasonic testing, radiography, magnetic particle testing, eddy current testing, thermographic testing, liquid penetrant testing, acoustic emission, and stress-strain Digital Image Correlation (DIC) testing. I also mentioned that the stress-strain DIC testing is relatively new, with potential for continuous improvement in this area.

In addition, I picked up this slide from an earlier lecture, where we say there are a total of six classifications, or six classes, of the crack. This is the linear crack, which will be treated as a volumetric crack to break the surface. Now this is the initial first crack, and the third crack is almost the same, but this crack is not on a surface. Therefore, we employ the term "near surface linear normal" to refer to the surface crack.

Now if I make an orientation of 90 degrees, the fourth class comes, which is also the near surface, which is below the surface but not on the surface. The same way we can have volumetric cracks, one is near the surface and another is slightly on the depth side. That is why we use the term subsurface volumetric crack. Now, just to detect these six types of cracks, we can use a number of techniques. We say that we can use a visual technique, a liquid penetration technique, a magnetic particle, ultrasonic, radiography, eddy current, thermography, acoustic emission, and, of course, the stress-resistant DIC testing. Now that we have given the numbers in this table, let us take an example. Here is a 0 number. 0 means this technique cannot be utilised at all, like the visual technique; we cannot see any crack that is not on a surface. It is just below the surface, or subsurface. So we're giving a 0 because this technique is unsuitable for these four types of cracks. Same thing for liquid penetration; liquid penetration is also basically a surface detection technique that cannot be used. If I try to cover even the 9-number stress-resistant DIC testing, that is also applicable only to the surface. So if I use a 9-number technique, I will also get a 0-0 number. Now coming to the 3 number, in this case we are giving the highest number as a 3. That means this 3 number variable technique is very good to detect this kind of crack.

Now, when the surface is breaking a linear curve because the size is much smaller, quite a possible visual technique may not be sufficient to utilize. So that is why we require some sort of addition, or there may be some additional equipment for that. So that is why we are giving here the 1 number, and the highest is a 3 as the worst is 0, 1 will be that may be it can be utilised, but we nearly required some more careful inspection. Coming to the 2, it would be somewhere better than 1 and then, but it is not as excellent as a 3. So these are the techniques for which we give numbers to the various techniques.

So that we can quantify the selection procedure. We can go ahead with the subjective selection; we can go ahead with the cost-simple selection, where whichever is the cheapest available, cost-economic available, or whichever is available or has the highest accuracy, I can select 1, but when the parameters are 3, 4, or 5, then the selection will turn out to be a little more involved. Again, we are giving these numbers based on some understanding, and as per my knowledge, every day there is a slight change in a technique. It may be that magnetic particles in the testing get in the way, the accuracy is improving, or the acoustic emission addition mechanism is improving. So that will take much less time to record the data, or the database the database may be continuously increasing. So today, whatever the number 2, it is getting in the surface breaking volumetric testing quite possible tomorrow, it will get a number 3.

These are tentative numbers provided purely for illustrative purposes to demonstrate how the selection procedure should be applied. The numbers mentioned are relative and based on a general understanding. For example, if the quality of graphic images is poor, or if the camera used isn't of high quality, the corresponding number might not be favorable. Conversely, if eddy current testing performs exceptionally well, it might receive a top rating, such as a 3. However, for non-conductive materials, eddy current testing would score a 0 because it cannot be used for such materials. Similarly, magnetic particle testing would score a 0 if the material is not ferromagnetic, as the technique would not be applicable.

To summarize this understanding, I have included three slides. Starting with visual inspection, which involves directly examining the object to detect cracks, corrosion, or abnormalities, there are also many videos available on various channels that demonstrate this technique. I'm referencing one such video here. Watching these videos can provide additional insights, and as I mentioned, there is ongoing research in this field. Therefore, the information in this lecture might change in the future, perhaps in as little as six months. The ratings and methods could be updated. If you intend to use this method for practical or industrial purposes, I recommend staying updated with the latest research and advancements in available techniques, as they may have improved compared to previous ones.

Now, in this case, as I earlier mentioned, we even try to look at it with our naked eyes, but we can really zoom in. We can really go ahead with an optical microscope, which can be added for that purpose. And another thing is that when we go for the testing naturally, the refinement is really happening to the process as well. You look at that the very bad weld joint has been shown in this and then the connection or may be with this joint, but quite possible we go better and better in the improvement in a welding joint itself. So even the visual technique that can be utilised for the present purpose of a current purpose is quite possible if there is good manufacturing happening; the visual technique may not be useful. So again, we really need to look at current research, current data, or current technique and how the equipment has improved, and based on that, we should go ahead with the selection procedure.

What procedure I am trying to explain in the present lecture will be applicable even in the future for the after 10 years or 15 years technique number with the number that we have been providing that may change to some extreme. Other testing we used was ultrasonic, which is a high frequency, which means a low wavelength, and means it can really go inside and find out the very fine flaws as well. So that is why that is very good for finding the flaws and even finding the material thickness, or over time, if the thickness is changing, that can be done and at least utilised.

Once again, I'm sharing a video link here that showcases some of the commonly available techniques on various websites and channels. By observing these, we can see how these methods are evolving and assign our own ratings to them. For example, radiography is a somewhat expensive technique that requires high-energy sources like X-rays or gamma rays. This method allows us to visualize flaws or defects throughout the entire body of an object. In the example shown, we're examining a tube to see how flaws are developing and assessing the quality of the welding. The technique enables us to view a 3D image of the flaw inside the object, providing a detailed understanding of the defect.

So this is very good, but again, as I mentioned, it may be the costlier one and may not be easy to really mount or immediately utilise in situ. So it may not be suitable, so it depends on what our requirements are and what the object is. So the technique's importance will change based on that. However, we really need a good understanding of the technique and method that we are going to use.

Once again, we've provided a link where you can watch videos that highlight recent improvements in these techniques. Similarly, we've included magnetic particle testing, demonstrating that this method is not limited to surface inspection but can also detect issues beneath the surface. If there's a crack with some depth, magnetic particle testing can help identify the problem. This technique is effective for both surface and subsurface inspection, provided the material is ferromagnetic. However, it won't work on non-ferromagnetic materials.

Eddy current testing, another technique, is highly cost-effective and has been in use for many years. The technology in this field has advanced significantly, especially in noise cancellation and the development of sensors, making it even more economical. As a result, eddy current testing is widely used and is capable of detecting both surface and near-surface defects.

The primary limitation in this case is conductivity—if the material is not conductive, eddy current testing won't be effective or usable. Similarly, if the material is non-ferromagnetic, magnetic particle testing cannot be applied. Thermographic testing, on the other hand, is very cost-effective and allows for the inspection of an entire surface in one go, providing a broad overview of potential issues. However, to capture fine details, significant filtration and post-processing are required, which demands good software and high-quality cameras.

Thermographic testing can still be useful for quickly identifying the location of faults. For example, in the case of a gear with multiple faults, a thermographic image can reveal where the problems lie. As I mentioned earlier, every surface emits thermal radiation, and cracks or discontinuities can disrupt the heat or temperature pattern, which can then be detected and analyzed.

As research in this area continues to advance, we can expect better and more sophisticated equipment to become available, allowing us to choose the most appropriate tools for the job.

We also have liquid penetrant testing, one of the most affordable methods, widely used across various applications. Here, a large patch of liquid dye indicates a significant flaw at a specific location. However, this method is limited to surface defects; it cannot be used to detect subsurface or near-surface issues. Therefore, liquid penetrant testing is suitable for identifying surface cracks, porosity, and localized defects.

Acoustic emission testing, which we covered in a previous lecture along with stress-strain Digital Image Correlation (DIC), works similarly to thermal emission. Acoustic emission is produced by different materials and processes, and it can be used to detect the initiation and propagation of cracks, coating damage, or delamination. This method provides signals that require careful capture and post-processing. If the appropriate tools are available, acoustic emission testing can be very effective. However, installing sensors can sometimes be challenging, especially when dealing with rotating elements, where a high signal-to-noise ratio is crucial compared to stationary units located further from the fault.

As for strain DIC, this is a more recent technique, primarily used for surfaces that are difficult to access. By capturing multiple images and computing the pattern, finite element methods can be applied to obtain good results. However, it is limited to surface analysis and doesn't provide accurate subsurface information.

While we've covered these nine techniques, it's important to note that they represent only a fraction of the available methods. Literature reviews often describe up to 50 different non-destructive testing (NDT) techniques. Rather than delving into every detail of NDT, our focus now shifts to selecting the most appropriate NDT method for a given purpose.

To do this, we'll use the weighted objective method, a type of optimization method. Although many optimization methods exist in the literature, for this course, we'll concentrate on the weighted objective method, which I'll explain in the next three or four slides.

Which method will be best for you? The NDT method can find and analyse the defect. So, finding is not only sufficient analyzing and kind of the defect and if it is possible the classify the defect that is a defect of flaws. Now, if it really meets all the quality standards, if it really matches, and if there are 30 flaws and we are able to find the 30 flaws, that makes a lot of sense to us. If there are 30 flaws and we are able to figure out only 15 naturally, whatever innovation capacity of what we are trying to improve the system, it will not improve that much because we are not getting all kinds of faults, or may be we are getting only bigger faults, not a smaller one. So, we are not really reaching to the root cause of failures, but we are able to figure out that some damage has already happened.

So, in that situation, almost all the flaws, if we are able to capture that method, will turn out to be the best, and we try to utilise this optimisation method for that purpose. That is why the entity method can find and analyse defects or flaws satisfying a specified quality standard. Whatever we are trying to set as a requirement, that method should be chosen. Now, sometimes people want an efficient method, or the efficiency of the method should be very high, and there is a need to really mention what the meaning of that is. So, I am just trying to show the examples. As you know, sometimes people say efficiency means how quickly an entity method can identify and evaluate a flaw or defect. How quickly we are able to diagnose a flaw that is really happening inside a surface or on the surface.

Sometime people say that the efficient method means it reduces inspection time, the inspection time is less, and output is very high. That means it is really giving a good output, almost all the faults, and people say that it is an efficient method. Sometime we worry about the cost, and often the mistake is that people talk about only the equipment cost, but what will be the staff cost? Because here the time that is taken will also be related to the staff cost. And then whether, really, without training, that equipment can be operated or whether we really require extensive training to operate that machine. That means if the person concerned is not there, the machine cannot be operated.

So, the staff the kind of the requirement of training and kind of involvement of the staff is required that also matters. And the last one is that the testing equipment is there, and the training person is also there, but this required very frequent maintenance; it was a minimum maintenance. Those things are important when we're trying to select this testing method. And one more thing is that the kind of precision and reliability we are going to get out of the results also need to be considered. Now what are the steps in the weighted objective method, which is a WO weighted objective method, and what are the relevant parameters for our purpose for the entity selection?

Now, what are the relevant parameters? It can be efficiency, quality assurance level, or difficulty level. We want the simplest equipment. We do not want very expensive equipment, but rather difficult equipment, maybe economic criteria, or maybe safety. Then, whenever the person is operating, he should be safe. As you know, there is a problem related to gamma rays, and some people do not want to get exposed to gamma rays, even x-rays. So, safety will come to mind, and then another one is time, or how quickly we want that. So, these are some parameters that need to be selected before starting the selection procedure, or, maybe, when we want to select the entity method in this case. However, the same procedure, or maybe a similar kind of parameter, will come when we go for the coating selection or we go for the tribometer testing, and then the selection of the tribometer meters, which are really available in many numbers, civil tribometers can be utilised for a general number of purposes, or maybe spiritualised tribometers can be utilised.

So, those things will also be important for us. What we are trying to do in this method is assign numerical weights. I have seen the many optimisation methods where they say that everything is the same weight, which means efficiency, importance, quality assurance importance, safety importance, and time importance. Everything is almost the same. We are not giving special weight to anything. In other scenarios, we can say now that safety is number 1 important, efficiency is number 2 important, and quality assurance is number 3 important.

So, we are ranking; that is what we need to quantify, and in this lecture, we are saying to assign numerical weights to each parameter, whichever is selected. So, that is, whether we want to give more importance to efficiency or to quality assurance. The selection method will be slightly different than the method that will be selected, which may also be different. So, these things need to be evaluated properly. Another one is that every entity technique will have merits and demerits; can we quantify that?

We can quantify, which is why we use the utility score to quantify the techniques. So, we will explain with one example. Then, finally, what is the overall score? We can give a ranking based on the 10 points, the 5 points, or the 100 points. I will be selecting the 10 point-based ranking that, out of 10, is the score of each technique that we are trying to select. And then the highest score may be selected if you want the highest value, or if you want the minimum value, the lowest value should be selected, which will be explained in this lecture.

Based on this method, we'll calculate an overall score and use it to select the most suitable non-destructive testing (NDT) technique. As mentioned earlier, the weighted objective method can also be applied to various other purposes, such as coating selection, destructive testing selection, or surface engineering approach selection. Once you understand this method, it can be adapted for other contexts.

Now, let's discuss the assumptions. We assume that different factors, such as efficiency, degree of difficulty, and cost, have varying levels of importance. These factors aren't treated equally; for example, time and hardness are not assigned the same value. This requires normalization to arrive at accurate rankings. We'll normalize the values so that the overall ranking falls within a range of 0 to 10, where 0 represents the worst outcome and 10 represents the best. This will form the basis of the entire method.

The weighted objective method provides a framework for comparing different NDT techniques by assigning numerical weights to various parameters, ultimately quantifying them. This approach helps minimize subjectivity and enhances objectivity by assigning numbers to parameters, leading to more reliable results.

To illustrate this, we'll examine a case study focused on welded joints, determining which technique is best for identifying flaws in these joints. Based on my experience, manual welding often results in multiple flaws. For example, in bridge construction where on-site welding is performed, the welded joints frequently contain several defects.

So, the beginning itself of the bridge has a flaw; naturally, after 5–6 years, the flaw will increase significantly, and there is a possibility of the bridge collapsing. So, that is why the maintenance of the bridge will increase significantly if these joints are not manufactured, or, maybe, made properly. So, we are trying to cover that kind of example. I am just not going for the bridge failure; we will just focus on the welded joints and what kind of flaws there are and how to diagnose those flaws. Now, what are the real parameters that should be selected? There is a possibility that we can choose efficiency; we can select quality assurance, degree of difficulty, economic criteria, safety, and time, and then this really needs to have numbers. So, maybe initially we have some testing done in our lab, then we can have a number. How will I pick up this number from the literature?

Now, what are the different entities that have been widely used for this purpose? The literature indicates that most of the five techniques have been extensively utilised for this purpose: ultrasonic testing, magnetic particle inspection testing, acoustic emission, radiography, and eddy current testing. So, these are the five techniques that have been utilised for the diagnosis of the welded junction. Now, what are the different kind of flaws in a welding junction?

Poor weld quality often occurs in manual welding due to the presence of inclusions and similar defects. During the welding process, issues like cracks, pores, or trapped gas bubbles can arise because the material undergoes melting and solidification on-site. There's also a chance that the temperature isn't evenly controlled, leading to areas with more cooling or heating, which can result in cavities forming as the weld fills the gap.

Another common problem is incomplete penetration, where the weld doesn't reach the required depth. This happens when solidification occurs before the molten material can fill the intended area, leading to a lack of fusion or incomplete penetration.

I've included some figures here that illustrate this issue. You can see examples of incomplete penetration, where the liquid metal hasn't reached certain areas. This results in a lack of sidewall fusion or inter-run fusion, where one layer doesn't fully bond with the next, leaving gaps or trapped inclusions. These inclusions can be caused by dirt, oil, or other contaminants.

So, inclusions are possible, which are coming along with the weld junction. We know that because of the inclusions, there is a possibility of a crack, and that it will grow when there is a possibility of corrosion, or maybe sacrifice corrosion, which happens. So, that may be initial, which is why we say inclusions are another possibility. Now you are able to see the gas bubbles. Small gas particles can form on a subsurface; they can also form on a surface during solidification. So, porosity is another possibility of defect, and when it really happens, one of the worst things is a kind of delamination. Now here the weld junction is coming from a top, and then there is a separation of the surface itself.

So, this kind of delamination happens now. Apart from this, there is the possibility of a transverse crack that is perpendicular to the weld direction, and a perpendicular crack along the weld direction that is a longitudinal crack. Now this crack can surface and can also penetrate into the inside. So, in this case, a visible visual inspection can also be done. However, we want to stick to these five methods, which have been extensively used to detect welding flaws. So, what kinds of different flaws am I trying to reframe? We say that when molten metal cools unevenly, it's not necessarily a problem if it cools evenly; it's usually the uneven cooling that creates a problem.

Even the liquid gets trapped in the weld itself. So, some where the solidification happens and some where the particles only know this liquid remains a trap inside. It is a possibility, and sometimes that is why we call it slag or inclusions. As a result, what will happen? It will weaken the area, and then it will really compromise the structure's integrity. So, wherever the flaw comes, it is going to compromise structural integrity, and another one is that to evaluate it naturally, we will require non-destructive testing. That is why we are giving a lot of importance to figuring out if there is any slag and if there is any existence of the slag.

So, if they are, then we can remove that defect, or maybe in the future we can fine-tune our welding procedure to minimise the slag formation. And as I am mentioning here, most of the failures I have seen, if they are automated, can be tuned very well because of the knowledge. However, the manual is subjective, which is why we can at least say that most of the defects in welding occur because of the improper procedure that is being followed. Sometimes we find it, and the unfortunate thing is that because of the high temperature, even the operator who is operating will not be able to really figure out how much porous porosity is being created there, if there is any lack of fusion, or if there is an undercut. These are the mistakes that remain because of the high temperature, and we say that it is not a comfortable environment as such for an operator.

I advocate for increasing automation in welding, although I recognize that it can be challenging and costly, which is why manual welding is still commonly used. However, when the complete welding procedure isn’t followed, issues like insufficient joint preparation, improper edge formation, or misaligned electrodes often occur.

Moreover, in environments where corrosion and erosion are factors, even minor defects from the welding process can grow into significant problems over time. Corrosion and erosion can exacerbate these defects, making them much more severe.

If we can evaluate these defects using non-destructive testing (NDT) methods, we can quickly repair or maintain the parts, ensuring they remain in good condition. However, there's also the possibility that during welding, foreign materials like dirt particles or oil could contaminate the weld. If not properly cleaned, or if high temperatures lead to the formation of oxides or sulfides, these contaminants can become inclusions in the surface, causing additional problems.

And as a figure, I showed that the lack of fusion may cause a major problem as an incomplete penetration. So, whatever the weld junction we want to make, we are not able to make it because of the incomplete penetration, and it becomes a serious weld problem that it is not reaching. It is possible that there is not really a separation, the possibility of delamination, or even the possibility of cracks at a number of places. Another one is because we sometimes use gases, and then in the gas environment, the gas bubbles also get interrupted, which causes porosity, and maybe the blow holes are one, and then sometime the blow holes become in chain form. So, like an air tube-type fault, this is also possible. And then another possibility, as particularly wherever it is getting attached to the other two different surfaces, then the crack at any one place. Initially, the crack will be there, and then it will continuously propagate.

So, it will cause more problems. Now, if the crack itself is like a cracker crack, which is bigger in size, like a more than metric crack, then more and more problems will be there. So, that is why, whatever the weld junction is manufactured and it is a must to get, we should repurpose the entity for that purpose. Now, let us start with our method, the welded objective method. In this case, I have taken five techniques: ultrasonic magnetic, acoustic, radiography, and eddy current. This does not mean that number one means ultrasonic is the best; I am just looking at a sequence.

So, I am not using the best of words in this phase. However, as I mentioned, we need to pick up the data either by performing experiments in our lab and getting data or by getting data from the literature. Occasionally, the data may not be readily available in the literature. However, we can digitise these curves. So, in my next lecture, I will be explaining how to digitise the existing curves and how to interpret the results. So, in this case what we have done efficiency ratio, that has been picked up from one literature that they mentioned efficiency ratio as a 1.4 for ultrasonic testing, magnetic particle testing efficiency ratio is a 1.99, acoustic emission is a slightly lesser in this ratio is a 0.88. So, the radiography test's 0.99 eddy current is 1.37. So, these are the picked-up data from the literature. The next one is the degree of difficulty of the method to be utilised: ultrasonic gets a 3.11, magnetic particle gets a 2.08, acoustic emission gets 4.07, radiography gets 4.31, and this gets 2.68. Now, if you see, we want this efficiency ratio to be increased. This ratio needs to be increased for better results.

However, the degree of difficulty needs to be minimized. Here, we want higher values for certain factors and lower values for others. If we focus solely on the efficiency ratio, magnetic particle testing stands out as the best option with a value of 1.99. When considering the degree of difficulty, which should be as low as possible, magnetic particle testing also emerges as the best choice.

Regarding cost per foot, based on data from a particular website, ultrasonic testing costs approximately $3,338 per foot, magnetic particle testing costs $3,568, acoustic emission costs around $10,000, radiography costs $3,730, and eddy current testing costs $2,000. From a cost perspective, eddy current testing is the most economical option, as lower costs are preferred.

When we consider setup time, which doesn't account for the full setup time in this explanation, magnetic particle testing again proves to be the most efficient, requiring only 2 minutes to set up. Ultrasonic testing and eddy current testing each take 3 minutes, while acoustic emission takes significantly longer at 20 minutes. However, this could change with advancements in acoustic emission methods, such as easier-to-mount sensors, which could reduce setup time to as little as 1-3 minutes.

Given these three parameters—efficiency ratio, degree of difficulty, and time—magnetic particle testing is generally the best option, except when considering cost, where eddy current testing is superior. The challenge lies in determining which parameter is most important: cost, time, or degree of difficulty. This is why the weighted objective method is essential.

To compile this data, we'll use MATLAB, as mentioned in a previous lecture. MATLAB will be provided free of charge to students enrolled in this course from July through October. We'll use MATLAB to create a complete table, employing a parameter matrix, where "ER" stands for efficiency ratio, "DOD" for degree of difficulty, "C" for cost, and "OT" for operating time. This matrix will help us organize and analyze the data more effectively.

So, here we are looking at only the operating point, not a complete point at a time, and what are the values 1.4, 3.11, 3.33, 3.8, and 3 that have been given in matrix form? So, this is a 4 by 5 matrix that has been given, and then we enter this kind of matrix that is going to come to us, right? So, this is what we can develop in MATLAB. So that we can quickly remember, we can judge or evaluate the importance of which method will be selected and which has the highest ranking. The second thing is, how do we decide whether time is more important, cost is more important, or maybe the degree of difficulty is more important?

So, what we do is use the word-digit logic method. What is the digit logic method? At a time, we will be comparing only two parameters. Even though we have four parameters at a time, we will be comparing only two parameters, and then in one situation, when we are writing parameter and we have written four parameters, we also need to take care that not a single parameter should get an absolute 0 value. That means the parameter will go out of line or out of the algorithm. So, that minimum value for the parameter should be at least 1 on the time scale, or maybe if I do a normalization, at least a 0.1 kind of value, or maybe less, but it all should be more than 0. So, in this digital logic method, what we do is make a table of the of the number of parameters. This is in the efficiency ratios of one parameter, the degree of difficulty, another parameter, cost, third parameter, time, and fourth parameter. Now here is the fifth parameter, which is not really there, but we are introducing a new one, which is a dummy parameter. In all cases, a dummy will get an absolute 0 0 value, and all other parameters will get at least some number relating to the dummy, or maybe one number compared to the dummy. So, how many columns will there be? We have several factors to consider. With 4 factors, we calculate the number of columns as follows: we multiply the number of factors by the number of parameters plus 1 (which gives us 5), and then divide by 2. This results in ((4*5) / 2), which accounts for the two parameters at the time we're analyzing.

So, the overall 10 columns. So, one column. 2 columns: 3 4 5 6 7 8 9 10. Now, what are we going to do in these columns? We will compare efficiency ratio and degree of difficulty, and then judge whether you require a higher importance to be given to efficiency ratio or whether you should be given to degree of difficulty. In this case, the efficiency ratio is more important compared to the degree of difficulty. So, I give one value to the efficiency ratio degree of difficulty, which is 0. The second efficiency ratio needs to be compared with a cost. Is the efficiency ratio more important compared to the cost? Yes, it should be more important compared to cost.

So, I've assigned this one number. However, depending on the situation, I may reverse it. As you know, efficiency is not as important as cost. So, this is a 1 and 0. Now coming to the third efficiency ratio, it should be compared with time. Is the efficiency ratio more important compared to the operating time? Now it is important. So, the efficiency ratio again gets a 1, and of course, compared to the dummy, almost all variables will get a 1.

So, this is the default efficiency ratio, where the dummy efficiency ratio will get a 1. Now this is a comparison among the four. When it comes to the degree of difficulty versus cost, I say the degree of difficulty may not be as important as the cost. So, I have given one parameter to cost. Another one: degree of difficulty versus time. We say now that time is more important than degree of difficulty.

Here’s how we calculate the weighting factors for each parameter:
- Time receives a score of 1, while the degree of difficulty scores 0. For comparison purposes, a dummy parameter receives a score of 1, and the dummy degree of difficulty gets a 0. Similarly, cost is more important than time, so it also receives a 1, with time receiving a 0 in comparison. The dummy cost gets a 1, while the dummy time gets a 0.

- Summing up these scores:
  - Time: 1 + 1 = 2
  - Degree of difficulty: 1 + 0 + 0 = 1
  - Cost: 1 + 1 + 1 = 3

- The total score is 2 + 1 + 3 = 6. Since the total possible score is 10, we divide each score by 10:
  - Time: 2/10 = 0.2
  - Degree of difficulty: 1/10 = 0.1
  - Cost: 3/10 = 0.3
  - Efficiency ratio: 4/10 = 0.4

This gives us the weighting factors: 0.4 for efficiency, 0.3 for cost, 0.2 for time, and 0.1 for the degree of difficulty. These weightings reflect the relative importance of each parameter, with efficiency receiving the highest weight and degree of difficulty the lowest.

This weighting is documented in the MATLAB code, where the relative importance of the parameters—Efficiency Ratio (ER), Degree of Difficulty (DOD), Cost (C), and Operating Time (OT)—is set as 0.4, 0.1, 0.3, and 0.2, respectively.

Next, we will establish the utility score for each parameter. For instance, we have the efficiency ratio values from literature:
- Ultrasonic Testing: 1.4
- Magnetic Particle Testing: 1.99
- Acoustic Emission: 0.88
- Radiography: 0.99
- Eddy Current Testing: 1.37

These values will need to be normalised, as they may have different units. To achieve this, we will use the utility score formula, focusing on the objective value for each parameter.

So, in this case, the ultrasonic testing objective value will be 1.4, the magnetic particle testing objective value will be 1.99, the acoustic emission objective value will be 0.88, the radiography testing objective value will be 0.99, and the and the ID current testing objective value will be 1.37. The next one is a minimum value. In this case, what is the minimum value? In this case, the minimum value is turning out to be 0.88. So, that will be the maximum value. A maximum value is 1.99 in this case. So, these values are given, and now we can also remove them. Instead of 0.1, I can go with a 1, which is a possibility, and then instead of 1.1, I can go ahead with a 1. However, it's important to note that, regardless of the method we've chosen—in this case, we've selected 5 numbers—there is a possibility of selecting 6 numbers, 7 numbers, or 10 numbers instead. So, still, there is a possibility of some technique that will get a lower number than this, and there is a possibility of a number that is higher than that. So, that means there is a possibility that some technique will be included that has a number or efficiency ratio less than 0.88, and then there is a possibility that the efficiency ratio of some testing will be greater than 1.99. So, we are just keeping to our scope. So, in the future, it may change.

So, that is why we have multiplied 1.1 with a maximum value and 0.9 with a minimum value. So, if we are leaving some sort of gap, it should not turn out to be 0 or 10; it will always be between 0 and 10. So, this is a method that we will be utilising again. This is further increasing the utility scope, which we need to maximise. However, if it turns out to be the minimisation, then I will do this whatever the calculated score, which I will be subtracting from a 10. So, what is this score minus the 10 minus this score that will give the minimum value?

Here's the approach we will use:
We have five techniques and will apply the utility score method to evaluate them. For each technique, we'll use a parametric matrix to assign objective values, iterating from 1 to 5 as needed. For instance, the matrix might assign values like 1.4, 1.99, 1.88, etc., for the efficiency ratio (ER).

After calculating the overall scores using MATLAB, we might get results such as 4.35 for ultrasonic testing and 3.4 for another technique. To simplify, we may round these numbers, though minor variations can occur. For example, if the exact score is 4.317, rounding might adjust it slightly.

In addition to evaluating efficiency, we also aim to minimize time and the degree of difficulty. As explained previously, the scores for these factors are subtracted from a maximum value of 10 to reflect their impact. This process allows us to derive utility scores based on the criteria and adjustments discussed.

So, this score minus 10 will also, maybe, be subtracted from a 10 and give us different results. Now, in this case, what we are saying is that ultrasonic testing gets, of course, a degree of difficulty level that we tabulated earlier in the literature as 3.11. Now, when we do this kind of normalisation, it gets around 5.6849, and then winding on to maybe the 2 level when we round off is a 5.68, and in this case it is a 9.275. As I mentioned earlier, we required a minimum time, and then magnetic particle testing is the best. If we do not use this kind of formula, maybe say 1.1 and 0.9, then we will be getting this value as a 10 because this is the best. However, we are leaving some scope; there is some method, or maybe some method, that we have not explored that may have a 10 value.

So, why should we choose this as a 10? That is why we are trying to slightly reduce it. Acoustic emission; otherwise, if this is an acoustic emission, radiography is the worst in this case 4.31. Otherwise, if we do not use this kind of formula, then what will happen is that the radiography test will get a 0 value. So, we want to avoid that now. We should not use a 0; we should not use a 10. That is why this formula has been utilised for that purpose.

Here are the utility scores for different testing methods:
- Ultrasonic Testing: 5.68
- Magnetic Particle Testing: Highest utility score of 9.275
- Acoustic Emission: 2.339
- Radiography: Lowest utility score of 1.503

These scores are obtained from solving the algorithm, whether using MATLAB or Excel, based on the given data. For the cost factor, our goal is to minimize the utility score. Therefore, we subtract the cost-related values from a maximum of 10. The utility scores for cost are calculated accordingly. For instance:
- Ultrasonic Testing: Costs around $3,338 per foot.
- Magnetic Particle Testing: Higher cost at $7,568 per foot.
- Eddy Current Testing: Lowest cost at $2,000 per foot.

Consequently, Eddy Current Testing receives the highest utility score of 9.782 due to its lower cost. Acoustic Emission Testing, with the highest cost, ranks lower in utility.

These figures are sourced from literature, but for more accurate results, conducting in-lab testing and considering the mean values and standard deviations from extensive literature reviews could provide refined data.

Now here, the acoustic emission is worst at 10000 and is giving a utility score of 1.08 or 1.086. So, this is a more or less common thing that will happen for the time factor 4 time, and in this case, the time again acoustic emission takes a maximum time, but we want to minimise whether this whole equation has been subtracted from a number 10. And then, if we look at three, ultrasonic testing is also taking 3 minutes, and eddy current is also taking 3 minutes. So, they should have the same value, and this is 9.405. 9.405 is the same value, and acoustic emission is a worst, which is why this is getting 0.99. Magnetic particle testing is the best, which is why it is getting 9.9 again. Now if there is a more and more difference, the value will naturally be nearer to 0 or nearer to another 10, but again, it will not be 0 or 10; it will be nearer or may be closer.

So, this is what we have done: we have four factors and five tests, and then we have done all the calculations.

The next step is to determine the overall ranking, which requires multiplying the weight. So, in this case, for ultrasonic in parameter 1, they got a rating of 4.35353, and the weighting factor of factor 1 is 0.4. So, that is why we multiplied, and then the next rating was 1/5.68 multiplied by 1. The third one was an 8.328 multiplied by 3, and the last one is a 9.4 utility score multiplied by 0.2. So, the overall rating comes out to be 6.688; it is an out of 10, and in a similar way, magnetic particles get a 7.4570; this is another one. Now acoustic emission somewhat gets the lowest value of 1.0093, of course. We can go ahead and round up to two numbers. Whatever the value we are getting from MATLAB, we are just coding and using that value.

So, now in the radiography, we are also getting a lower number less than 5; it is 5.475, and the last one is an eddy current that is getting around 7.168 1.7.1868. The question comes: which technique is the best? If I go with a numerical value, the numerical value will say that magnetic particles are going to be the best, and then overall MATLAB code for this purpose has also been written.

Now we can say the best suited for the welding testing purpose is magnetic particle testing, and it has been extensively studied in a literature. Wherever there is this kind of welding fault, magnetic particle testing is done extensively, and if you want an overall ranking, the magnetic particle has the highest one. Then eddy current, ultrasonic radiography, and acoustic emission come last. Now, when we go ahead, we also need to look at the faults. We have seen a number of faults, which may be surface, may be near surface, but may be subsurface as well. If there are some surface faults, what will happen? So, we need to look at this kind of matrix again, and for the surface-related matrix, we are getting 3 rank for the magnetic particle.

So, another thing is that it is also for the fact that magnetic materials. If there is aluminium welding, will I be using this method? We need to really think from that angle. The second one is the number of eddy currents coming. If the material is not conductive, will I be using this technique? So, this is important to rethink, and another thing is: what will happen if there are surface cracks and subsurface cracks? Also, what kind of method should I choose? Here it has been shown that for the surface cracks and then even subsurface deep cracks, the eddy currents are good. So, the question comes: do I go ahead with both together? Shall I use magnetic particle testing as well as eddy current testing? That is what you need to choose in the measure on the numerical method? I can say the magnetic particle is really giving the best result.

However, there is some subjectivity involved as the numbers are derived from literature. Both Magnetic Particle Testing and Eddy Current Testing show similar results. Given this, I will consider both methods for our purposes, applying each one based on the literature data. After conducting a few iterations, I will determine which method is most effective for detecting faults in welding joints specific to our company or training environment.

If the faults or cracks are primarily subsurface, I will likely favor Eddy Current Testing due to its suitability for detecting such issues.

If the cracks are primarily on the surface, I would choose Magnetic Particle Testing. For materials that are not ferromagnetic, Eddy Current Testing would be more suitable. If the material is neither conductive nor ferromagnetic, Ultrasonic Testing would be the appropriate choice. The selection method depends on the material and its limitations.

As we approach the final slide of this lecture, let's review the potential welding issues. We rank possible defects as follows: cracks, undercuts, and tearing (which resembles delamination and is the most severe). Other potential issues include overlap and porosity.

Ultrasonic Testing can detect all these issues. Magnetic Particle Testing, however, is limited to ferromagnetic materials and cannot detect tearing or defects below or far from the surface. Acoustic Emission Testing is not very effective for detecting porosity or overlap as the signals can become disturbed, leading to less accurate results. Eddy Current Testing cannot be used for non-conductive materials unless specific surface treatments are applied.

Overall, with a solid understanding of these techniques, you can choose the most suitable method based on the material and the defects you need to identify. If no single technique fits perfectly, you can consider combining methods or developing new approaches using your creativity and available resources. In the next lecture, we will discuss advancements in the selection process and how to refine these techniques. Thank you for attending, and I look forward to continuing with Lecture 22.