Welding Engineering
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Module - 08
Weldability of Metal
Lecture - 04
Failure analysis and prevention

So, this is the fourth lecture on the weldability of metals of the eighth module and in this presentation mainly we will be taking up the failure analysis and the prevention approach. we know that we are use variety of the engineering components in our daily life to help in our daily activities at the same time these engineering components are also used for manufacturing the systems and in production of the vehicles in production of the power.

So, so many engineering components are being used for variety of the purposes, and whenever failure of the any component or complete assembly takes place the disruption is observed. So, what we want that whatever engineering component is working and is in place that should keep on working and it whenever we get time for the regular scheduled maintenance that is repaired and replaced, but in absence of the proper repair and replacement schedule and strategy sometimes unplanned the failure of the component takes place.

So, whenever sudden failure of the component occurs it becomes necessary to investigate it properly. So, that its reoccurrence in the future can be avoided. So, main objective of this presentation is to see that, what is the general approach regarding the failure analysis of any engineering component including the weld joints and how can we identify the root causes for the failure root, causes for the failure of a particular component. So, that its reoccurrence in future can be avoided. So, we will be starting with the presentation, which will be comprising.

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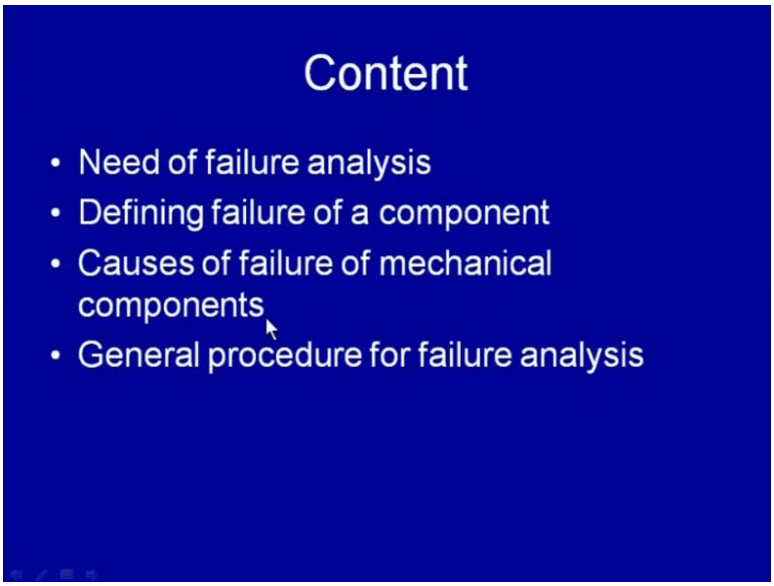

The need of the failure analysis this is the first part and then defining the failure when component when can we consider that component has failed and the causes of the failure of the mechanical component and the general procedure for the failure analysis. In this presentation mainly we will be taking up the failure the approach, which is used for the failure analysis of the mechanical component and especially the metallurgical failure of the mechanical component. So, why we need to carry out the failure analysis.

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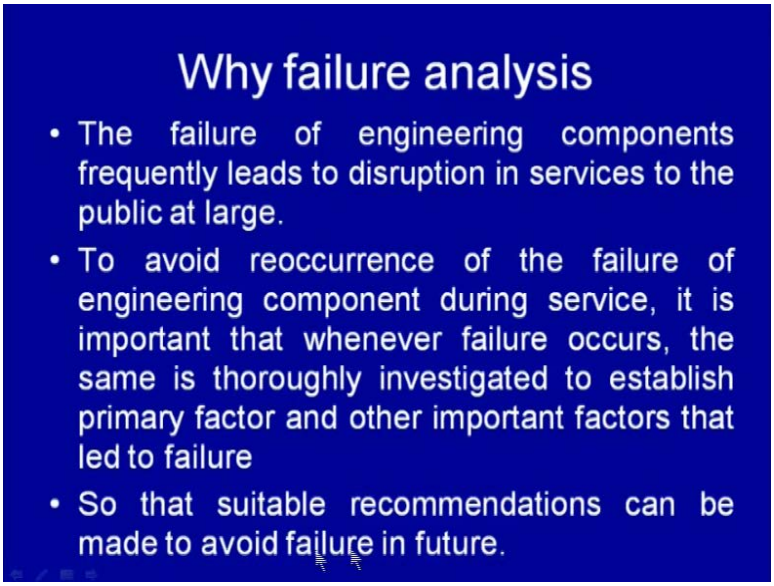

We know that whenever failure of an engineering component takes place the services are

disrupted and public do not get those services on time as per requirement. So, to avoid such kind of reoccurrence of the failures of the engineering component during the service it becomes important that the thorough investigation of the failure is carried out. So, as to establish the primary factor or other important factor that has contributed towards its failure, and once if it is established that factors, which have contributed towards the failure of a particular component then proper precaution can be taken to avoid the reoccurrence of the failure of that kind .

So, once the failure investigation reveals the primary causes and the important factors that have led to the failure of a particular component then suitable recommendations are made. So, as to avoid their failure again in future what it involves basically a systematic approach or step by step methodology is used in the failure analysis, which helps in establishing the sequence of events, which have led to the failure at the same time it also helps in establishing the primary factors and the causes, which have contributed towards the failure of particular engineering component.

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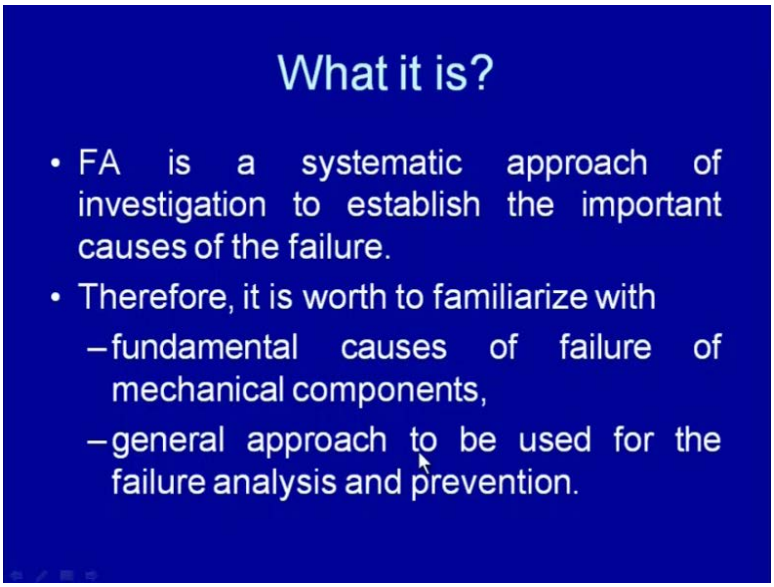

So, the failure analysis is a systematic approach of the investigation to establish the important causes of the failure and to do this it becomes worse to familiarize this, what are the fundamental causes of the failure of the mechanical component and what general approach we can use for the failure analysis and prevention.

So, the fundamental causes of the failure of the mechanical component there’re certain

set of the factors that usually contribute towards the failure of the mechanical component and it becomes important to know that what are those factors and these factors mostly are related with the design of component the material, which has been used fabrication of that component manufacturing process, which has been used for development of that particular component and the processing parameters, which have been used for manufacturing that component and the service conditions under, which that component has performed and subsequently has failed during the service.

So, it becomes important to look into the that particular mechanical component, which has failed and though what are the common causes as far as mechanical failure of the mechanical component is concerned. So, we will be talking about some fundamental causes of the failure of mechanical component apart from that we will be also looking into the step by step approach, which is used for the failure analysis of any metallurgical failure of a mechanical component.

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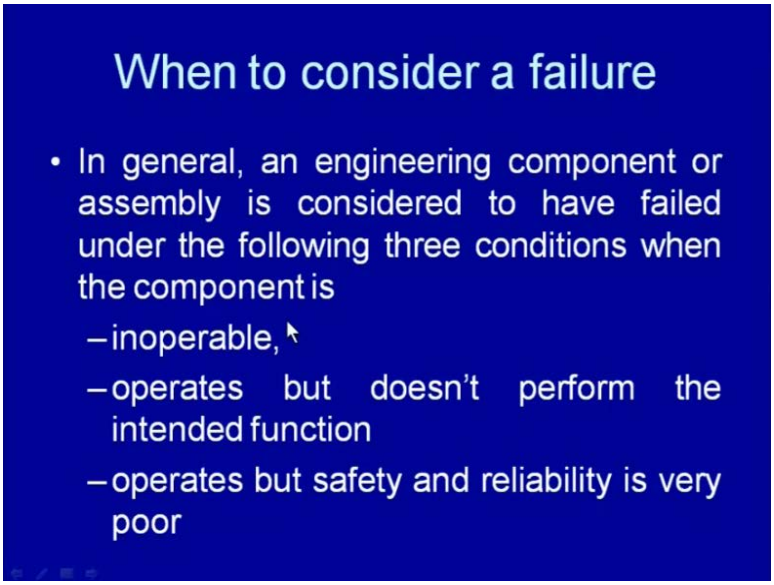

So, in general any engineering component or the assembly is considered to have failed under the following three conditions means what are the situations, when we can say that a particular assembly or the component has failed. There can be three kind of situations when a particular component is inoperable means it is not able to perform the intended function then we can say that component has failed or when the component operates, but it does not perform the intended function.

So, the component is operating, but it is not giving the desired results then also we can say that component has failed or the assembly has failed or when the use of a particular component compromises significantly with the safety and the reliability during the service and under those conditions also we can assume that component has failed. For example, the crack in particular component has grown to such an extent that its further use can compromise with the safety and the reliability of the component in the service. Therefore, either it should be repaired properly or it should be replaced in time. So, these are the three conditions under, which whatever is the kind of the component whether it is weld joint or the part of a particular assembly the components can be considered to have failed under these conditions.

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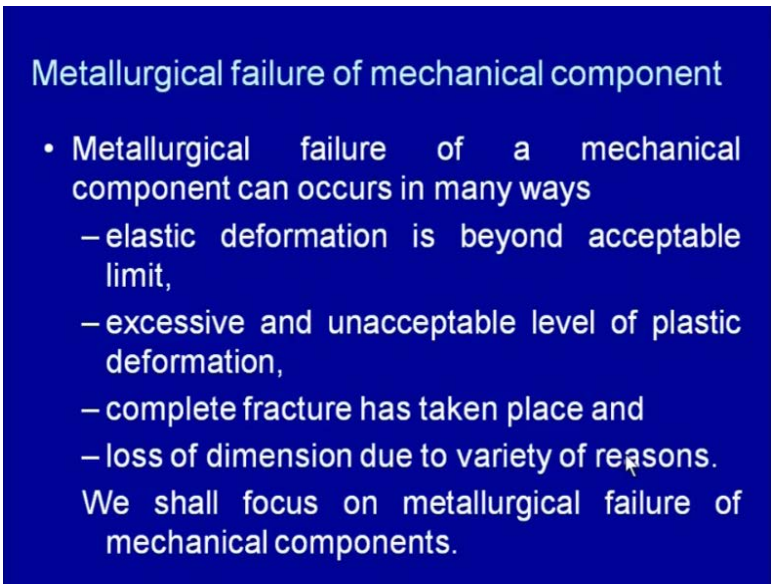

As far as mechanical metallurgical failure of the mechanical component is concerned there can be the three different types of the situations, three or four kind of situations, where we can consider that metallurgical failure of the mechanical component has taken place and it can occur in many ways. Say, when the weld joint or the mechanical component is subjected to the elastic deformation beyond the acceptable limits and this is adversely affecting the performance of the component during the service or it is going beyond the acceptable limit of the plastic deformation means the loading is such that the component is being deformed plastically beyond the acceptable limits and adversely effecting the performance of the engineering component.

Then also we can say that metallurgical failure of the mechanical component has taken place and the third situation, where complete fracture of the component has taken place during the service either due to the sudden load cyclic loading or over loading of the component. So, in this case complete separation of the component into the two or more pieces takes place there may be one more situation, where during the service component loses its dimension due to the variety of reasons and these reasons are mostly related with the wear like component is subjected to the adhesive, abrasive, solid particle erosion or cavitation, corrosion or variety of the forms of the wear, which are commonly encountered by the mechanical component during the service.

So, all these can contribute in changing the dimensions of the component during the service and the loss of the dimensions of the component beyond the acceptable limits can lead to the malfunctioning of the component during the service. So, then also we can say that component has failed. In this particular presentation mainly we will be focusing on the metallurgical failure of the mechanical components as far as causes of the failures are concerned these fundamental causes of the failure of the mechanical component. we know that we have a very wide range of the engineering components, which are made of variety of materials using variety of processes and are used in very different, and wide range of the service conditions, and because of this we need to consider that the failure analysis for each component, which has failed unique approach is adopted.

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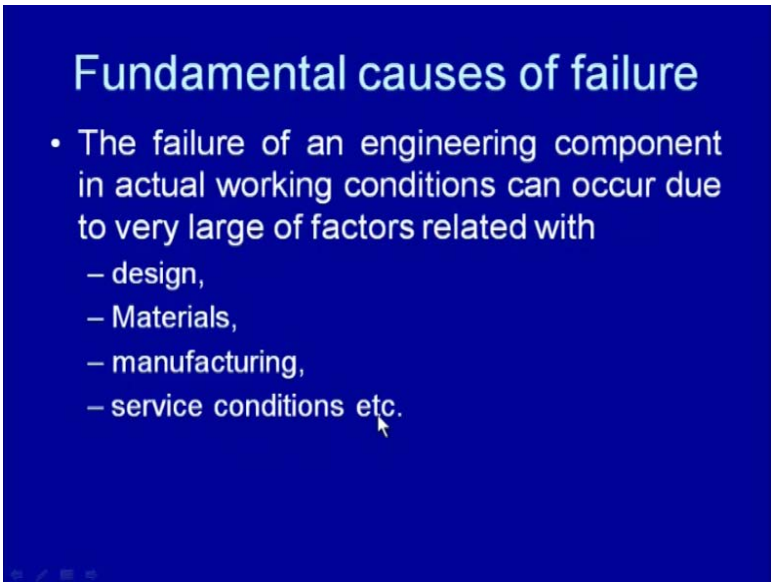

So, the failure of the engineering component under the actual working conditions can occur due to very large number of the factors, which can be related with the design of the component like there may be design deficiency in the design of the component itself. Because of, which it could not perform under the given load conditions, given service conditions or there may be deficiency related with the materials like material is not able to withstand under the service conditions, and this can lead to the premature failure of the component or the weld joint during the service.

Then the manufacturing process is not efficient or as per the recommendation. For example, if is it was recommended that for the aluminum welding helium or argon should be used, but instead of that if the carbon dioxide with the some percentage of oxygen is being used then that can lead to have the number of discontinuities and defect in the weld joint. So, there can be various the situations, where manufacturing related process parameters can introduce discontinuities in the weld joints and the if the component, which is being manufactured and that can be the source of the failure of the component and the service conditions also vary ranging from very study load to the fluctuating loads at room temperature then the low temperature to the very high temperature conditions under very normal environmental conditions to the very severe corrosive or saline environmental conditions.

So, due to the wide range of the service conditions, if the component has not been designed and has not been made using the correct kind of material then it is premature failure also can take place due to the service abnormal service conditions, which are being experienced by during the service. So, need to you see why should we go through the these fundamental causes of the failure, because if it is important to see that what are the basic factors related with the mechanical components that frequently contribute towards its failure if we know.

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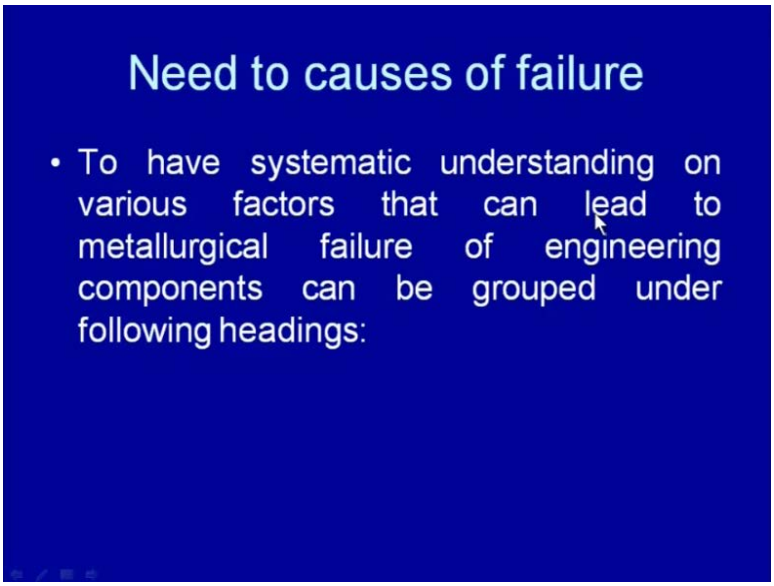

If we have the systematic understanding on the various factors that can lead to the metallurgical failure of an engineering component then we will have we can give the systematic thought about what are the things that can contribute towards the failure of component, and that can help us in a systematic investigation of the particular failure.

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So, the fundamental factors that lead to the metallurgical failure of an engineering component can be grouped under the different headings, these headings include like improper design. Whatever, engineering component or the weld joint has been designed

its design is deficient means there they are lot of stress raisers or the material the design criteria, which has been used is not sufficient for the long performance of the component during the service. There may be variety of things related with the deficient design or improper design, improper selection of the material, which has been used for developing a particular component is not appropriate.

Because of its inability to withstand under the service conditions, which will be experienced by the component during the service and that can lead to the very premature failure of the component many a times due to the lack of awareness about what kind of the service conditions will be and what kind of stresses will be acting in the component during and the service. So, those factors lead to the improper selection of the material for development of particular component or the defects and discontinuities present in the material itself means the material, which is being used for developing a particular assembly or the component is defective and inherently.

It is having the discontinuities like the presence of the inclusions in large quantity in the steel sheets causes the lamellar tearing. And so, those are the kind of problems, which are related with the presence of discontinuities in the metal itself. Similarly, the presence of high amount of the hydrogen in dissolved state in the steels can contribute to the hydrogen induced cracking in the weld joints made of the hard enable steels.

So, those are the things like, which are present or the discontinuities or the defects or the undesirable features, which are present in the metal itself and contributing significantly towards the failure of the component. Improper processing of the material means the processing parameters, which have been recommended are not either proper or they are not being exactly followed for the processing of the material.

For example, if the particular steel is subject is suppose to be heat treated at the 800 degree centigrade followed by the rapid quenching and then tempering at 300 degree centigrade, but either the temperature nor the time recommended time values for the heat treatment are being followed then that can lead to either the excessive hardening or the softening of the material, then the and this can lead to have the properties, which are not expected in the particular engineering components.

So, in lack of the proper processing parameters can lead to have the number of undesirable features, and which can be the source of the failure in the poor service

conditions this is poor service conditions are about that the service conditions, which are for which a component is being exposed can lead to the failure. If the conditions, for which it is being exposed are such that the component has not been designed for those conditions.

For example, mild steel weld joint can be successfully used under the normal ambient conditions, but if it is used under the subzero conditions minus below 20 degree centigrade then it will be showing great reduction in toughness and it can fail in very brittle manner and will not be able to perform the function, which is intended. Similarly, if something is expected to work under the ambient conditions and if the high exposure is, if the exposure is given at a high temperature then under the creep conditions. It will change its dimensions and that can lead to the premature failure of the component.

Then the poor assembling like the proper, if in absence of the proper assembling procedures or the like of the carelessness on the part of the workmanship or the workers who are working leading to the improper alignment or improper kind of fit between the melting components.

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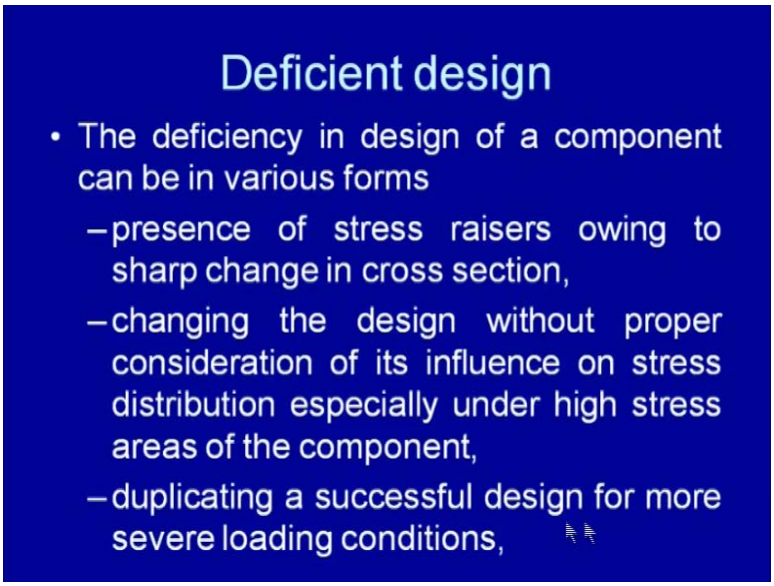

If those things are present then that can lead to the premature failure of the component, poor maintenance, proper maintenance schedule is also not being followed either it is not there or if it is there then it is not sure that what is to be done, who will do, what he will do, what he will check and how it will be done. So, lack of the strategy about the

maintenance also leads to the failure of the many mechanical component especially, where there is a relative movement between the components involved.

Then each factor will be taken up one by one as far as the fundamental factors contributing towards the failure of the component like the first one deficiency in the design or the design is deficient and how it can lead to the failure of a particular component. Whether, it is a weld joint or any engineering component if its design is deficient then under the service load conditions it can lead to the failure like too much means the presence of the stress raisers due to the sharp change in cross section. Very common example is the fillet weld at the toe of the fillet weld, if the proper bead geometry is not maintained then it becomes source of the high stress concentration and frequently failure under the fatigue load conditions take place from the toe of the weld.

So, that those kind of stress raisers must be avoided and the changing the design without prior consideration to its influence on the stress distribution especially under the high stress areas. This can be like modifying the design of the component without giving proper thought that how it can affect the stress distribution and if the stress distribution especially is modified unintentionally in the high stress areas, then it can become the source of the high stress concentration it can become the source of failure, because it will be nucleating cracks easily in those areas, and the once the crack is nucleated then it can lead to the failure easily.

Another possibility is that one design is very is doing is very successful and for one set of the conditions and keeping in mind, if the same design is duplicated for more severe conditions then it can also perform, it can also fail under the severe load conditions. Because it was not designed for the severe load conditions, but it was designed basically for the somewhat lower service conditions, but and the under the lower level of the service conditions it was successful, but if the same design is duplicated without giving full consideration to the kind of stresses that will be generated under the severe load conditions then it can lead to premature failure of the component as far as deficient design is concerned.

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Then the design is developed without full knowledge of the stress conditions due to the complexity of the geometry. Some of the component design of the some of the components is so complex that it becomes difficult to really understand that what is the magnitude and what will be the nature of the stresses in the particular area then how the sizing of the component can be done. So, it becomes under those conditions when it is difficult to find out really a stress conditions that will be experienced by the component under the external load due to the complexity of the geometry.

Then those then the failure of those components can be expected, and then inability to use a proper design criteria. So, if the service conditions are unexpected or the or we or the designer is not very much aware of the what kind of conditions can be expected during the service by a particular engineering component then he is not able to really select the proper design criteria for developing the design of the engineering component if it is. So, then it can lead to the premature failure especially under the conditions when it comes across the severe service conditions for which it has not been designed.

Then another important factor that can lead to the failure of engineering component or the weld joint is the improper selection of the material. This improper selection of the material like selection of material for developing the design of mechanical component in light of the operating conditions should be based on failure mechanism like, which material should be selected for developing the design of particular component that

should be based on particular failure mechanism for which it can be subjected means there will be particular mechanism through which component is expected to fail more than the other mechanisms, and that will be governed by the kind of service conditions for which it will be exposed, and these failure mechanisms can be the ductile or brittle failure it can be creep, it can be fatigue, it can be corrosion or variety of forms of wear like abrasion, adhesion, erosion etcetera.

So, material should be designed keeping these requirements of the failure mechanisms for which are, which can contribute towards the failure of the components. So, these failure expected failure mechanisms should be kept in mind while selecting the suitable design criteria. And so, selecting the suitable material for developing the design of particular mechanical component.

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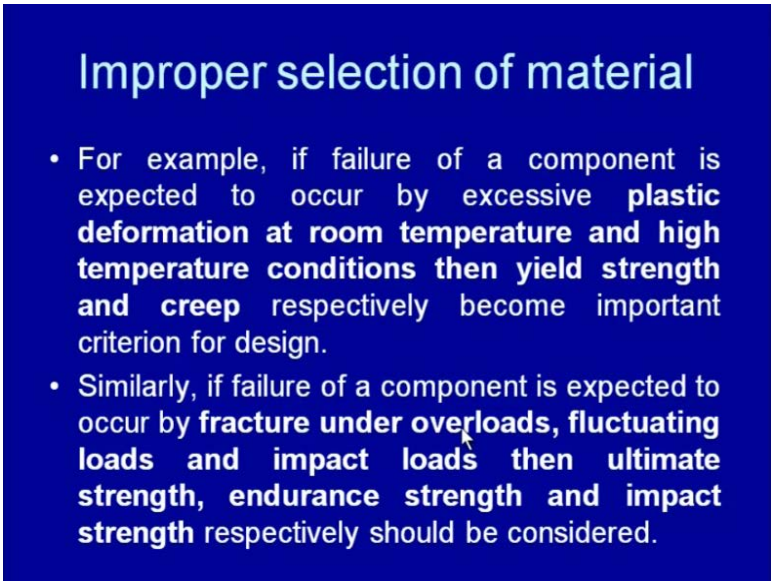

For each type of the expected failure of the mechanism a combination of the mechanical, physical and chemical properties are expected to be there in the material, which is being selected for developing a design. So, such kind of material means based on the kind of expected mechanism of the failure the material, which is to be selected should have certain set of mechanical, physical and chemical properties and therefore, it is important to consider that say for example what is the expected failure mechanism for a particular component during the service that is kept in mind while selecting the particular material.

For example, if the failure of the component is expected to occur by the excessive plastic

deformation at room temperature then yield strength should be used as a criteria, and if the if it is expected that failure will occur at the high temperature due to the deformation at the high temperature that the creep should be used as a criteria creep resistance should be used as criteria for selection of the material. Similarly, the failure of the component is expected to occur by fracture under the overload or fracture under the fluctuating loads or fracture under the impact loads then the ultimate strength endurance strength and the impact strength respectively, should be considered for selecting the suitable kind of material.

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Failure mechanism	Design criteria
Ductile fracture	Yield strength (tension, compression etc.)
Brittle fracture	Fracture toughness (K_{1c}), notch toughness, ductility, DBTT
Fatigue	Endurance limit / fatigue strength with stress raiser, hardness
Thermal fatigue	Ductility, peak plastic strain (under operating conditions)
Creep	Creep rate at given temperature
Plastic deform.	Yield strength
SCC	K_{1SCC}, corrosion resistance to sp. environment

If say this table shows variety of the expected failure mechanisms variety of the failure mechanisms under, which a particular component can fail during this service and a suitable design criteria. So, based on these the properties of the material suitable material should be selected for example, if the material is expected to fail in the by the ductile fracture then the yield strength should be the design criteria according to the yield strength in tension compression shear depending upon the nature of the load, which can act on the component then the brittle fracture, if the brittle fracture is a possible criteria and then the fracture toughness like the k one c notch toughness ductility and ductile to brittle transition temperature is the particular temperature at which there will be draw certain change in the toughness of the material and it decreases abruptly from the high value to the low value.

So, that temperature band at which this sudden change takes place is called ductile to brittle transition temperature then the fatigue, if the component is expected to fail by the fatigue then the endurance limit and the fatigue strength of the material with the stress raisers should be used as a design criteria, and the hardness should also be considered, because it dictates significantly the basic crack nucleation and the growth stages of the fatigue fracture.

Then the thermal fatigue for the thermal fatigue we need to consider the ductility and the kind of plastic strain, which will be experienced for a given the range of the cyclic temperature variation or the given temperature variation, which can occur during the service. Then the creep is expected failure mechanism and the creep rate at the given temperature should be considered, and then plastic deformation yield strength should be considered, and then for a stress corrosion cracking the k one s c c that is the stress insensitive factor in the stress corrosion environment this one should be considered and the corrosion resistance to the specific environment in which component is expected should be considered. So, based on the expected failure mechanisms suitable material should have the desired set of the properties. So that, it can perform successfully during the service, but if we are not able to do that sometimes.

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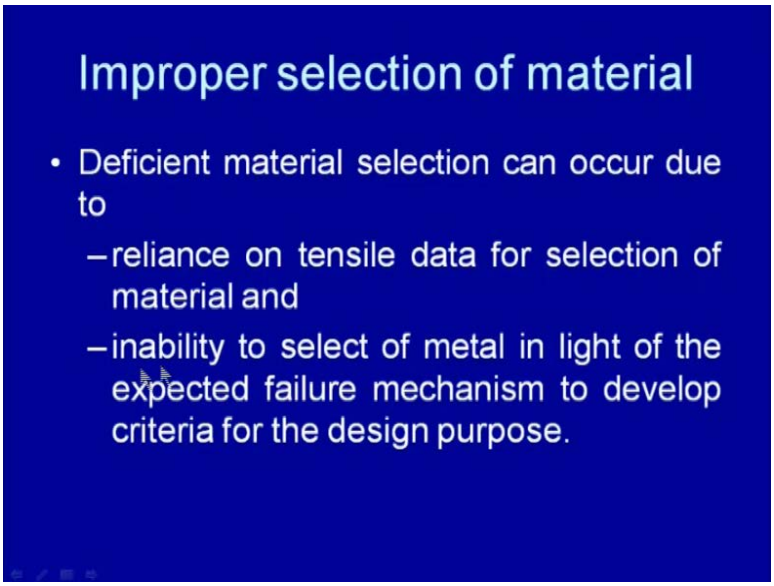

Due to the inability to select the material means deficiency in the material selection can occur due to the reliance on the tensile data. Many times we find that the property of the

kind of material, which is available or which is a potential material we do not have the properties desired. For example, creep resistance or the ductile to brittle transition temperature or the fatigue resistance or the impact resistance means the properties of the particular material, which is to be selected, are not available in respect of the design criteria.

So, most of the time we rely on the tensile data related with the material for its selection, and this kind of the reliance on the tensile data is found insufficient especially for the successful performance of the component. Therefore, it becomes important that the material to be selected must be characterized for the properties, which is important for the performance of the component based on the design criteria.

And the second one is inability to select the metal in light of the expected failure mechanism to develop the criteria for the design purpose means we are not able to really finalize or decide, which will be the most expected failure mechanism under the given service conditions then that can also lead to the inappropriate selection or the deficiency in material selection.

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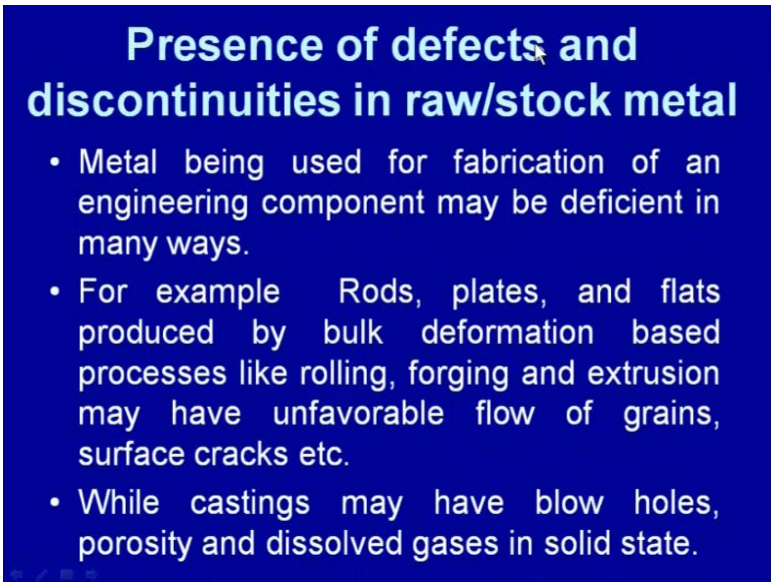

So, these are the two important factors that lead to the improper selection of the material then the presence of the defects in the discontinuities in the raw stocks. We know that the raw material in form of the sheets, rods and the ingots is developed using variety of the processes and these rods, plates, flats produced by the bulk deformation processes by

rolling, forging, extrusion etcetera. Many a times have unfavorable correct features in form of the undesirable grain, flow direction, surface cracks, inclusions, lamellas etcetera, and in case of castings these discontinuities are present in form of blow hole porosity ,dissolved gases and if these components, which are available are the as a raw material with the discontinuities.

If these are used for developing the other engineering components, which can be subjected to the mechanical loads and another service conditions during the service then these presence of these discontinuities in the raw material in the stock itself can lead to the premature failure of the engineering component.

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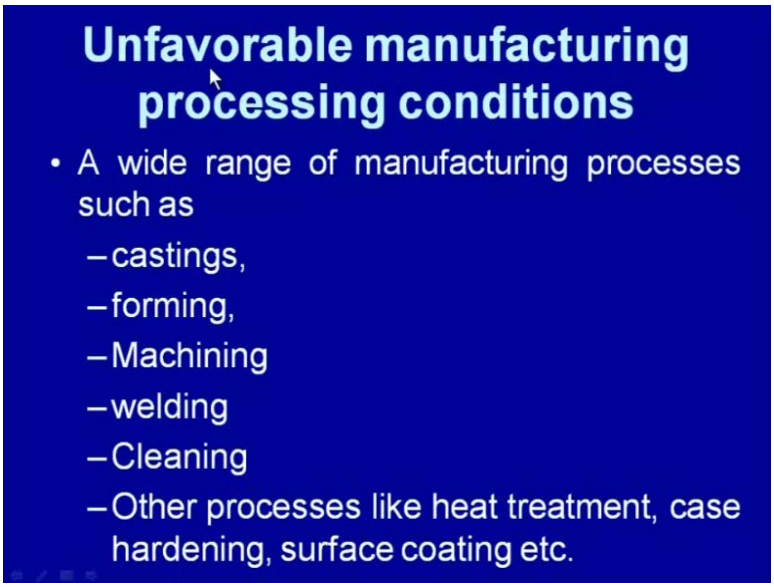

Then the unfavorable service or manufacturing processing conditions. For example, we know that a wide range of manufacturing processes are used for developing the engineering components ,which can be casting, forming, machining, welding, cleaning and other processes like for property enhancement like heat treatment, case hardening and the surface coating inappropriate selection of the processing parameters related with these manufacturing process can lead to the development of the undesirable features in the engineering component, and those undesirable features frequently form the source of the weakness or the stress raiser and initiate the fracture.

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So, the selection of the inappropriate combination of the processing parameters for each of the above mentioned manufacturing process can lead to the development of discontinuities, defects and the unfavorable metallurgical changes leading to have the undesirable mechanical properties in the component, which is being developed or these discontinuities will be forming the source of weakness and nucleating the cracks and helping their propagation especially under the external load conditions that will be leading to a premature failure of the component.

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These imperfections discontinuities are mostly processes specific and can exist in variety of forms due to the improper selection of the manufacturing process and their parameters. For example, in welding mostly we will find craters, solidification cracking, cracks in partial melted zone or the weld toe these are the typical features, which are associated with the welding only.

While in case of the castings we will find the blow holes, the porosity, piping defect. While in case of the forged components there may be surface cracks undesirable flow of the grains. So, many discontinuities and the defects are process specific and which forms the basis for the either stress concentration or for easy nucleation of the crack and the fracture of the component.

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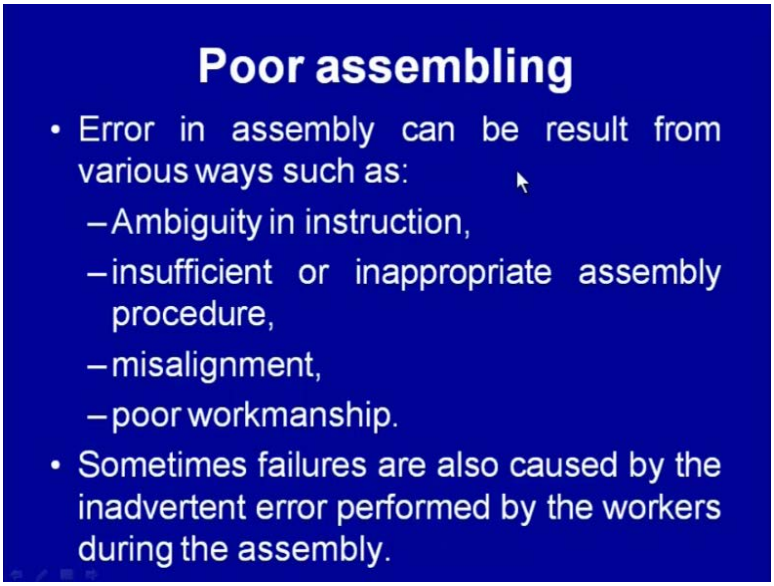

The poor assembly can be the source of the failure mainly due to the misalignment or inappropriate assembly procedure, which is being used for putting the different items together or proper assembly is being developed due to the ambiguity in instructions, which are to be used for assembling the component or the poor workmanship.

If these features are present then in proper assembly will lead to the malfunctioning of the component and that can lead to the premature failure of the component during the service. Sometimes the failure are also caused by the inadvertent error performed by the workers during the assembly, if everything is fine as far as procedure is concerned for developing the assembly, but the carelessness on the part of the worker or the inadvertent

error being performed by the worker can lead to the deficiency in the assembly.

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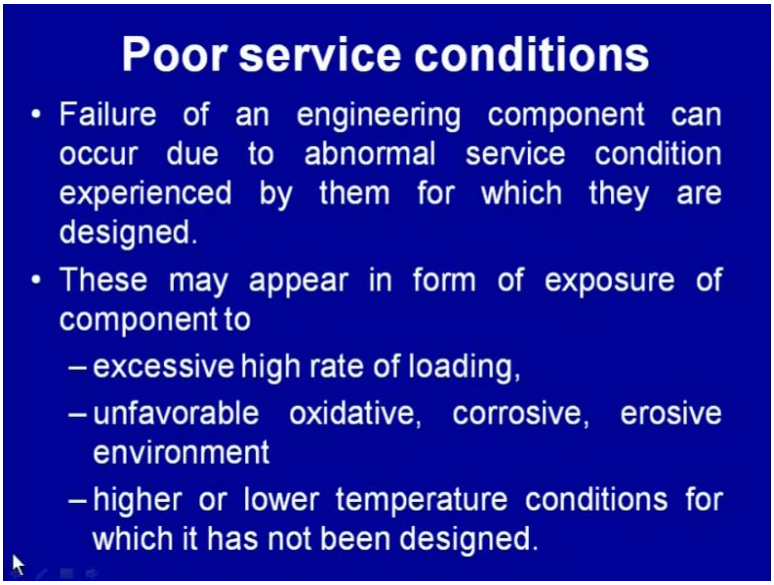

Many a times the failure of the engineering component can occur due to the abnormal service conditions experienced by them for which they are designed and these may be in form of the exposure of the component either to the excessive high rate of the loading. So, means this factor is mainly related with the conditions, which will be experienced by the component during the service for which it has not been designed though as soon as it comes across the conditions for which it has not been designed the failure is promoted.

So, means the exposure of the component to the abnormal service conditions can promote to the failure of the component due to the poor service conditions, and this poor service conditions may be inform of the excessive high rate of the loading leading to the embrittlement of the component unfavorable oxidative, corrosive and erosive environment leading to the either degradation of the material dimensions over a period of time and in developing the stress raisers on the surface of the component or exposure of the component either to the excessively high or the to the lower temperature conditions for which it has not been designed.

So, the exposure to the high temperature will be leading to the deterioration in mechanical performance, and that can lead to the failure due to either elastic or plastic deformation or complete fracture. Similarly, exposure to the lower temperature can lead to the catastrophic failure due to the loss of the toughness of the material especially in

case of the weld joint.

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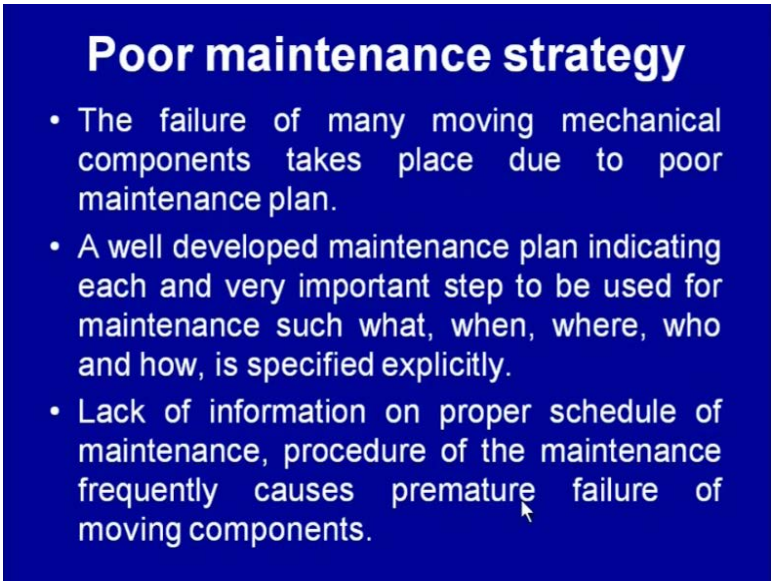

Then the poor maintenance strategy of can lead to the failure of many moving mechanical components, if the maintenance strategy is not being followed or if it is not there in the proper form. So, a well developed maintenance plan indicating the each and every important step to be used for the maintenance such that what will be done, when will be done and where the maintenance will be performed, who will do it and how the maintenance will be performed, if these things are not mentioned specifically then it can lead to the premature failure of the component. So, the lack of information on proper schedule of the maintenance proper procedure of the maintenance frequently causes the premature failure of the moving components especially.

Now, we will be talking about the general procedure, which is used for the failure analysis after going through these fundamental causes we will be able to know that if the failure of particular engineering component is taking place then we would like to see whether its design was perfect, whether proper material has been used, whether manufacturing process has been proper or whether service conditions for which it has been exposed were correct or proper maintenance has been done, whether this is proper assembly was developed or not.

So, these causes will help us in looking into the different ways that what can be the reason behind the failure of a particular component. So, the it will be worth or it will be

important to. So, the understanding on the different fundamental causes of the failure of the mechanical component will help significantly in the failure analysis. The general guideline, which is used for general procedure, which is used for the failure analysis .

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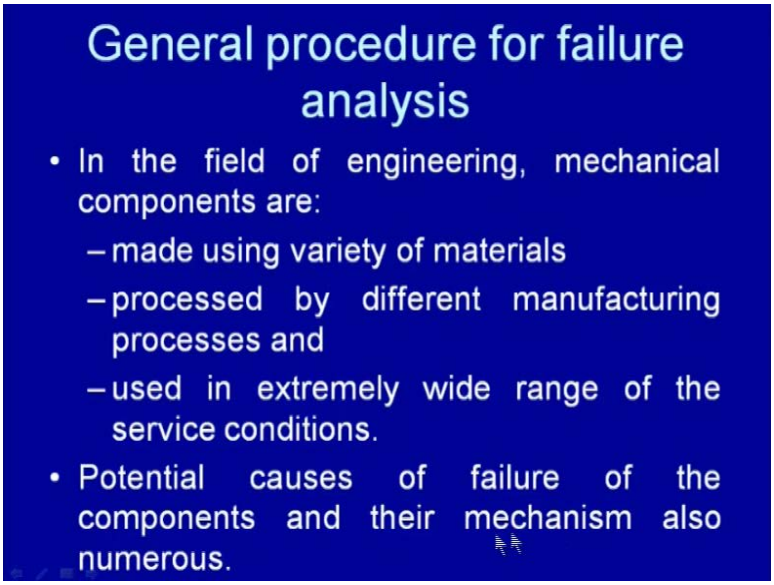

Will be talked in the some of the slides, which will be coming up. We know that in the field of engineering mechanical components are made of wide range of the materials ranging from the plastics to the aluminum, steel, copper and means titanium. So, very wide range of the metal systems are there and these are processes using a very wide range of the manufacturing process ranging from welding, casting, forming to the advance manufacturing processes, and then these are used to extremely wide range of the service conditions.

So, the kind of material, which is there the manufacturing process being used and the service conditions for which these are exposed are very wide, and because of this the potential causes of the failure of the component and their mechanisms are also very large and very numerous.

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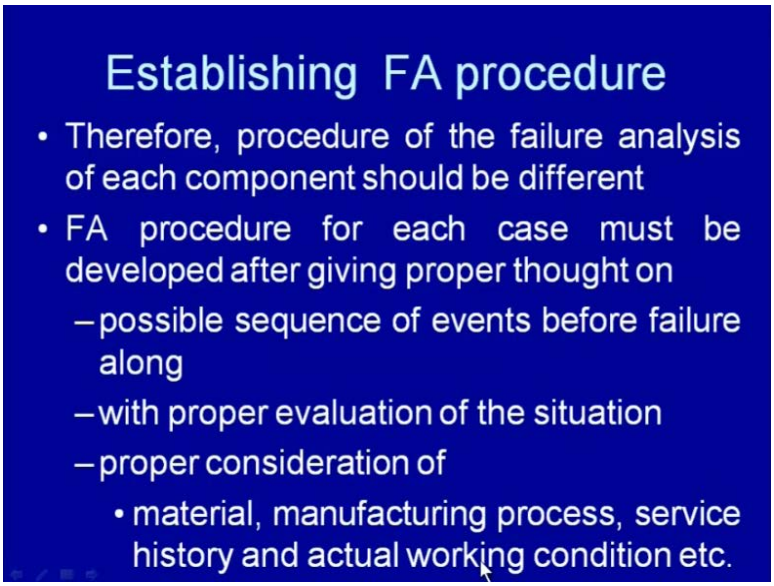

So, therefore procedure of the failure analysis of each component should be different and unique failure procedure should be adopted for failure investigation for each failure investigation. So, failure procedure failure analysis procedure for each case must be developed after giving proper consideration and thought on we need to look into what had lead to the failure of the component like the possible sequence of events before the failure along with we need to look into also the proper evaluation of the situation, and then we need to see the and give the proper consideration to the material, which was involved in failure manufacturing process, which one used for developing that component service history of the component and the actual working conditions under, which it was exposed.

So, these are the things, which should be kept in mind while initially checking out the plan for the failure analysis procedure, and each case must be given a proper thought to these aspects before going ahead with the failure analysis, and because of this one precautionary note is that

Hurriedness should be avoided, because it has been observed that on receipt of the failed component failure analyst tends to jump into the conclusion based on the half information, and tries to prepare the sample for metallographic studies to look or to explore the deficiency in the material itself.

So, this is the common tendency that the failure analysis analyst tends to jump into the conclusions through the half information and tries to look into the deficiency in the material itself through the metallographic examination. This kind of hurriedness should be avoided; because once the sample is prepared we can lose many vital clues, evidences and the information that can be present on the fractured component.

So, to avoid. So, this kind of quickness is uncalled for and in this process of the sample preparation for the metallographic studies, vital clues, evidences and information can be lost from the surface of the fractured component. So, any kind of hurriedness in the failure analysis on receipt of information about the failure or receipt of the failure sample should be avoided.

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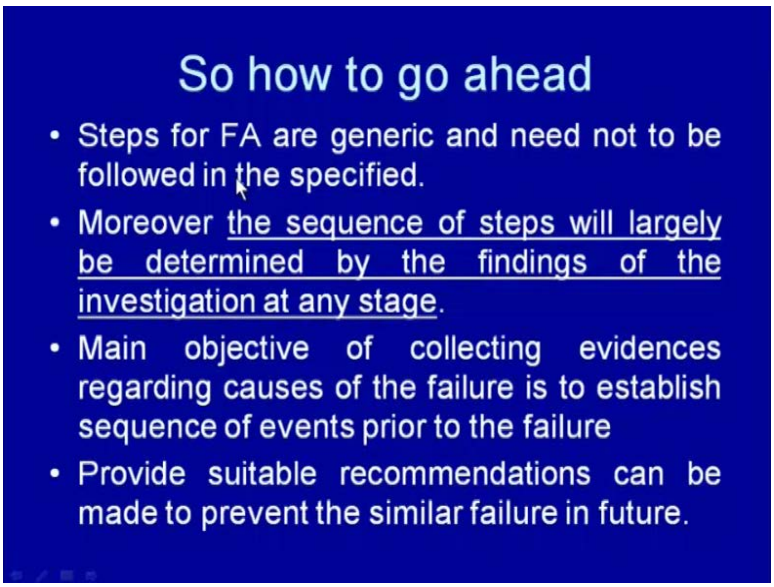

So, how to move ahead with this precautionary note how to go ahead step by step for the failure analysis, which is there should be followed and for that proper strategy should be chalked out based on the sequence of events, which can led to the failure or the kind of

the material the processes and the service conditions, which were involved under, which the failure has taken place.

So, there fourteen steps which are related with the failure analysis procedure and, but these steps are very generic in nature and it is not required that these are followed in sequence based on the need and based on the outcome of the analysis or the investigation of particular stage further investigation direction of the further investigation is decided. So, the steps for the failure analysis are generic and need not to be followed in a specified manner moreover the sequence of steps will largely be determined by the findings of the investigation at any stage.

So, say we are at a particular stage. So, finding of this stage will give the indication in which direction we should move further and one by one various possibilities are ruled out, which can lead to the failure of the component the main objective of the failure analysis is to collect the evidences regarding the causes of the failure. So, that we can establish the sequence of events, which have taken place prior to the failure.

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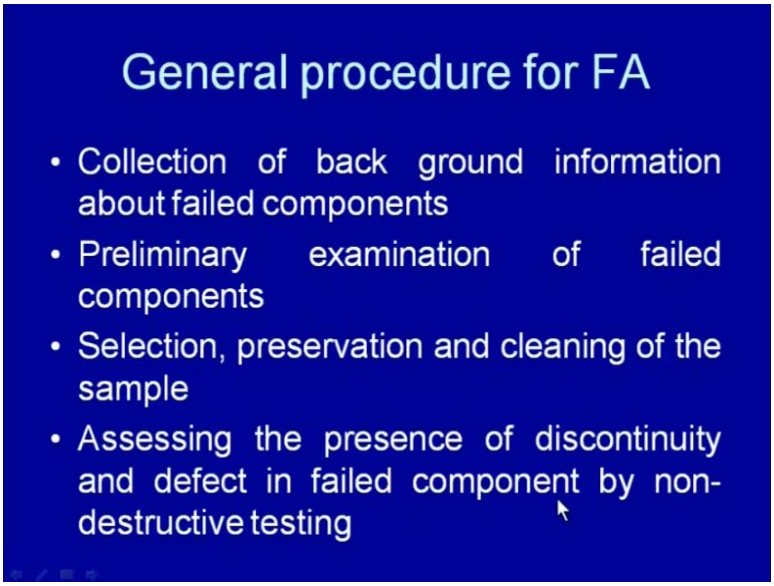

So, basically the objective is to see that what collect the information about the events, which have taken place prior to the failure and the subsequently that had led to the failure of the component. So, that once if you are able to establish that sequence of events led leading to the failure of particular component this will help in developing the suitable recommendations to a prevent the similar kind of failure in future. So, the

general procedure for the failure of the failure analysis of an engineering component including weld joint will involve.

First step is to see the collection of the background information about the failed component. So, in this system basically we collect the information about the design of the component, the material of the component, manufacturing procedure used for the component and the service conditions, which have been for which component has been exposed many a times all the data is not available. So, whatever information and data is available from the records that should be collected.

So, that we can be aware of what material was there and what kind of mechanical stresses for which it has been exposed during the manufacturing, say during, the rolling, forging or forming then what kind of the thermal stresses have been exposed or the has been given to the material like heat treatment welding or any other thermal treatment, and then what kind of the cleaning procedure has been adopted in the fabrication in course of the fabrication like it was a mechanical cleaning or the chemical cleaning.

Sometimes chemical cleaning induces the hydrogen and can lead to the failure of the components. So, proper information is collected about the various aspects and after collecting this information we will be familiar with what was the design, what material was used for making the component, what manufacturing processes were used, what were the service conditions used.

Thereafter, preliminary examination of the failed component is performed. Preliminary examination of the failed component will help us to see after the failure, where the parts were found, what was the location of the failed parts and where the fragmented parts were found after the failure, what was the location of the assembly, where failure has taken place or which part of the assembly has failed.

So, these are the kind of examination means information collected by during the preliminary examination of the failed component and proper record of the photograph of the components, where they were found just after the accident or the failure should be recorded. So, that subsequently if something is found that some sabotage was there then that can lead to the legal implications.

So, in order to have the proper evidence the proper record of the photographs of the

different components, where they were found after the fracture should be recorded then the selection, preservation and cleaning of the sample. Once if we know that what are the different components, which have been effected by the failure, where they were found after the failure we need to see that from, which location we should select the sample for the studies.

So, sample selection can be close to the fracture surface or it can be away from the fracture location and the for this purpose we can use mechanical or thermal methods. If thermal methods are used then the location of the cut should be away from the location of the interest then the preservation of the component many a times we find that after the failure the samples are in very bad shape with the lot of dust dirt oil burns etcetera. So, all those things are kept are should be preserved, because these can give the important clue or the information or the direction for the further investigation.

So, efforts should be made not to clean them, but in any case if the cleaning is required then the dry air can be used for the cleaning purpose and whatever the impurities or the things are present on the fracture surface those should be preserved for subsequent analysis, because these can give the important direction in the failure investigation in future.

Then the presence of then assessing the presence of discontinuities and the defect in the failed component by the n d t, once if we get the samples from the failed component either from the these samples can be from the fracture surface means location close to the fracture surface or from the locations away from the fracture surface. So, we can perform the non destructive test like the dye penetrate test, magnetic particle test or radiography test or ultrasonic test.

In order to investigate, if any internal discontinuity is present in the failed component or if or if the component is deficient, because if the discontinuities are present even in the locations away from the fracture surface that will indicate that material itself was deficient or having the discontinuities. So, to establish the presence of any discontinuity we can perform the non destructive testing's onto the samples, which have been taken from both the locations whether it is close to the fracture surface or away from the fracture .

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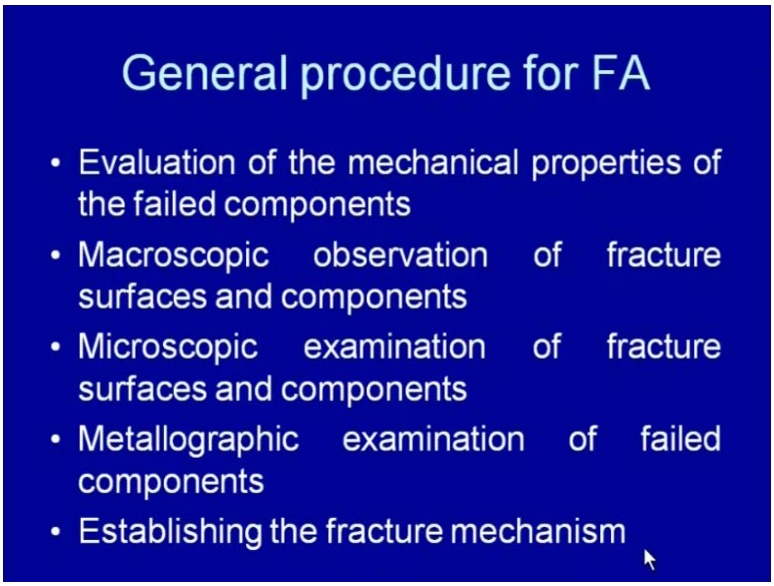

Surface then evaluation of the mechanical properties of the failed component. So, mechanical properties like destructive these are the destructive test, mechanical properties of the samples taken from the location close to the fracture surface and that away from the fracture surface can be performed in form of the hardness test, tensile test, fracture toughness test and objective of these test is to see whether the material, which was made for a particular component was having the desired set of the mechanical properties or not, if there is a deficiency in the mechanical properties of the material taken from the region close to the fracture surface then the kind of properties it should have for that kind of service, then it will indicate the material was the that the material was not having the desired set of the mechanical properties for the successful performance under the service conditions for which it was exposed.

So, this mechanical properties of the failed samples are mainly used to see whether it was capable to perform under the service conditions or not. Further, these mechanical properties can also be use to confirm whether the correct kind of material was used or the correct kind of manufacturing processes, where there and correct kind of the post treatments like heat treatment or the stress reliving treatments were performed or not.

So, whether all the things with the material as far as material is concerned from mechanical point of view over proper or not that also can be cross checked by the mechanical properties of the material, but this one very difficult sometimes it is found

very difficult to have the big sample from the locations close to the fracture surface that is why we are not in position many times to conduct the tensile test, fatigue test or creep test of the samples taken from the location close to the fracture surface and most of the time we rely on the hardness test.

So, it is common to take the small piece of the a sample from the location close to the fracture surface on which hardness test can be conducted and from the hardness test we try to estimate the kind of mechanical tensile properties and the other the tensile properties, and yield strength of the material. So that, some useful inferences can be obtained regarding the material regarding the kind of the manufacturing processes, which have been used on the material, which has or the component, which has failed then the microscopic observations the next step can be their microscopic observation on the fracture surface and the component.

Microscopic observation on the fracture surface of the component is performed using low magnification lenses and the magnification or stereo microscope magnification will be below the 50 x and it can be range 1 to 50 x means 50 times of the magnification can be range of 1 to 50 x and when it is performed it gives us very useful information about the stress state in which the failure of the component has taken place means it whether it was under the plain stress conditions or the plain strained conditions.

So, the fracture surface macroscopic observation of the failed component will indicate the stress state under, which failure has taken place then it will show the location from, where fracture has taken place whether it was from the heat affected zone, whether it is from the weld zone or from the base material in case of the weld joints and same time it will show whether the fracture location was close to the toe of the weld or at the location, where there was a sharp stress raiser like hole or the key way in the mechanical component. So, the microscopic examination will give us idea about, where from fracture has taken place means, which location has acted as a site of the stress concentration and the weakness and has triggered the fracture.

At the same time this will also show that the initiation site the fracture initiation, location, where from fracture has initiated, and then in which direction crack has grown, basically chevron marks are observed on the fractured surface. And so, the direction opposite to the chevron marks indicates the direction in which crack has grown during

the failure and these chevron marks basically converge towards the direction, where from the fracture has initiated.

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So, these chevron marks are nothing just like these can be shown in form of this the component then the chevron marks will indicate in this way these can be in form of like the fragments like this. So, this the chevron marks indicate that the fracture has initiated from this location and it has grown in this direction. So, bit these features can be observed only at the low magnification or using the macroscopy not by the microscopy. So, this will microscopic observation will give idea about the stress state under, which failure has taken place the location from, where failure has taken place the fracture initiation site and the direction in which crack has propagated.

So, this these information cannot be observed using the microscopy only the microscopic can give us these vital information about or if something else is present like the paint or the oil or some oxidation on the fracture surfaces has been observed then it will indicate how long time this crack was initiated and which might have contributed towards the failure.

That the microscopic examination will indicate the kind of microscopic mechanism, which was involved in fracture of the component these mechanisms are mainly four kind and these are like the dimple fracture, where very conical shape cavities on the fracture surface are observed these. So, the dimple fracture is one, which will be showing that the

whether fracture is ductile or the brittle.

So, the dimple fracture indicates the ductile fracture, and then the brittle fracture will be indicated by the features like the intergranular fracture or the presence of the cleavage facets. So, the cleavage facets presence of cleavage facets on the fracture surface through the microscopic examination will indicate the brittle fracture and the intergranular fracture will be represented by the complete the grain morphology present on the fracture surface under the microscope that can be observed. So, indicating the intergranular fracture.

So, both cleavage fracture cleavage facets and the intergranular fracture will be indicating the brittle fracture while the presence of dimples on the fracture surface will be indicating the ductile fracture, and then the typical striation marks on the fracture surface like this are also are observed, if this is the say component, which has been failed by the fatigue then we will be able to see these very step by step at microscopic level the concentric circles are being developed indicating the presence of striations this is the typical feature of the fatigue fracture. So, the striations on the fracture surface at high magnification means more than 1000. So, will be observed in the component fracture surface, which has been subjected to the fatigue.

So, the dimple fracture indicating the ductile fracture and represent of the cleavage facets and the intergranular fracture will be indicating the brittle fracture the striations will indicate the fracture then the metallographic observation of the field sample is also done, which will show that whether if the microscopic discontinuities present in the material, which has failed or it will show that whether the metal was correct kind or not whether the manufacturing process were used properly or not or any kind of adverse effect has been there in the material during the service or not. For example, in form of corrosion in form of decarburization, in form of the grain coarsening or any other say other affect, which can be there in the component during the service.

So, all that can be verified through metallographic examination further image analysis of the metallographic microstructure can give us the information about if the grain coarsening has taken place during the exposure or the kind of the micro structural features, which are present in the component then the establishing the fracture mechanism like, if the defect was already there in the material component then in light of

the service load conditions whether it should fail with those with the presence of the those discontinuities or not.

So, fracture mechanics basically helps to establish that whether a given size of the crack or discontinuities should have been stable or not. Under the given load service conditions and for given set of the material properties, because fracture mechanics is nicely relates the material properties, the external service conditions and the discontinuities present in the given material. So, if for a given size of the discontinuities in the material for the given service conditions and given fracture toughness of the material whether and given stress conditions it should have performed successfully or not.

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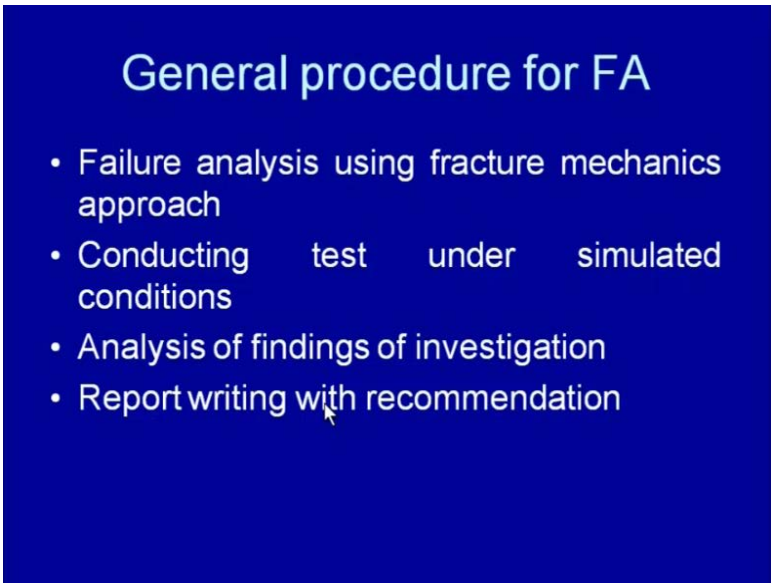

So, that kind of failure analysis is performed using the fracture mechanics approach, then sometimes we conduct the test under the simulated conditions also like, if the performance of the component has failed either in very low temperature conditions, very high temperature or in high temperature conditions then in order to assist the performance of the material under those conditions sometimes simulated tests are conducted.

These are very specialized test, which will be performed under the conditions in the material, which has failed and the simulated conditions are developed say, if the cavitation is taking place under the very low temperature conditions then the during the service then the cavitation test is conducted under the load service conditions. Similarly,

if the high particle height solid particle erosion is taking place at high temperature then we need to conduct the solid particle erosion under those conditions.

So, this will help us in establishing the behavior of the material under the surface conditions for which it can be exposed during the service then all these findings are analyzed to see that what could have led to the failure of the component. So, that the conclusion regarding the failure analysis can be made to identify what could have been the main causes that could have led to the failure of the component.

So, after the analysis of the various evidences and the findings of the investigation we try to establish the sequence of events that can that had led to the failure of the component, and this will help us in establishing whether there was a deficiency in the material design of the component or the deficiency in the materials or the deficiency in the manufacturing processes assembly or the maintenance plan.

So, what had led to the failure of the component over that particular aspect is identified. So, basically through this we try to identify that the some main factors that have contributed towards the failure of the component apart from the other factors and once we are reading with the analysis the report is written and in the report of the failure analysis should include the some important factors that could have led to the failure of the component along with the sequence of events, which has taken place before the failure and at the same time the report should also include what should have been done to avoid the recurrence of this kind of failure.

So, now this was the last step as far as the general procedure for the failure analysis is concerned. Now, i will summarize this presentation in this presentation mainly we have talked about the need to know about the failure analysis and the prevention approach, and then what are the fundamental causes of the failure or metallurgical failure of the mechanical component that commonly contribute towards its failure, and then we have also try to see what general procedure can be used for the failure analysis of the components. So, that important causes of the failure can be established in order to avoid the recurrence of the failure of the component.

Thank you for your attention.