Mathematical Modeling of Manufacturing Processes

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Lecture - 04
Evaluation of Properties and Process Modelling

The last part of this first module is the Evaluation of the Properties of Manufacture Products that is the one component I will try to cover in this part and second one is the Statistical and Data Driven Modeling Approach normally we follow if we collect some data. So this 2 part we will try to cover.

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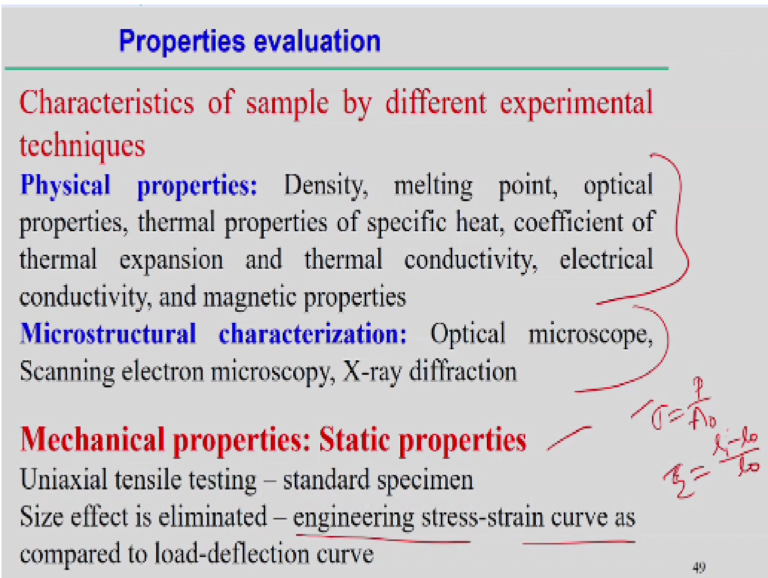

First look into that properties evaluation. So we have already discuss about the different properties normally we will consider to test the quality or performance of a manufacture product, but how we can conduct this experiments just to get some overall view on that. So properties evaluation in the sense that basically characteristics of the sample by different experimental techniques.

And then how we can do that we can do either to evaluate the physical properties for example density, melting point, optical properties, thermal properties of the specific heat, coefficient of heat transfer thermal expansion, conductivity electrical, conductivity and magnetic properties. These all are the physical properties there is a standard methodology and that following the standard methodology test methods we can evaluate all this properties.

But this properties is more important before applying any manufacturing processes, but once we apply some manufacturing process to get certain product and after that then we can evaluate the other properties for example in most of the cases we test the microstructural characterization and then for microstructural characterization normally we follow using the optical microscope or maybe high resolution microscope scanning electron microscopy or in some cases some properties we can evaluate simply using the principle of the x-ray diffraction technique.

So this are the other techniques we normally evaluate the properties in a manufacture component are course. Now out of this properties one by one we will try to discuss this and first we look into the mechanical properties this is the most commonly used mechanical performance of a manufacture component to evaluate that we do the mechanical testing and then mechanical properties can be evaluate either in the static properties.

We can evaluate the static properties for example if we apply the uniaxial tensile testing facility and there we use some standard size of the specimen and then once the standard size of the specimen according to the different standardization techniques and of course the size effect we normally produce uniaxial test we can represents the load versus deflection data when you conduct the uniaxial tensile testing of a simple.

But the size effect can be eliminated by using that load divided by the cross sectional area of the sample and of course the deflection what is the deflection or deformation happens that with respect to the original length if we make the relative measure of this thing in that way then we can eliminate the size effect and then that normally represents it in terms of the stress strain curve.

So that means stress is defined simply the load/original cross sectional area and strain which is divided by change in the length say l1-l0 with respect to original length so that stress and strain we can represents and of course that is size effect can be eliminated and that is as compared to the load versus deflection curve in uniaxial tensile testing. So what information we can get from the stress strain diagram or mechanical testing of a sample.

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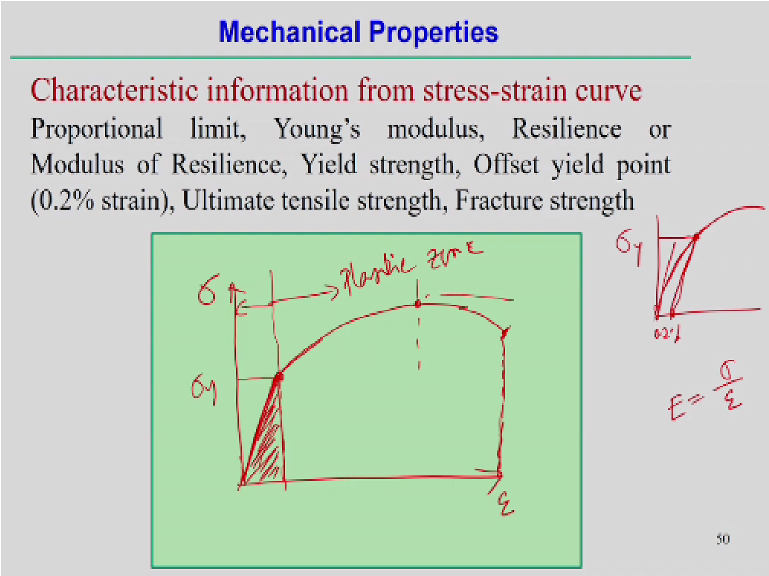

So the characteristic information from the stress-strain diagram we can evaluate the proportional limit, Young modulus, resilience or modulus of resilience all this information Young for example yield strength and offset yield strength of course ultimate tensile strength, fracture strength all kind of information we can get from a standard tensile specimen. So suppose we assume that this is a typical stress-strain diagram.

So first one is a linear component and then it is a engineering stress-strain diagram this is the optimum point and then fracture happens at this point so we can represent the strain, the stress. So this is the standard diagram stress versus strain that we can get from uniaxial tensile testing of a specimen, but what information from this tested diagram we can extract. First is the proportional limit.

So up to certain point the deformation behavior of a particular component is the stress is proportional to the strain and represented by a linear line. So that we can say this is correspond to the elastic strength and this corresponds to the yield strength value. So once just cross the yield strength value then permanent deformation happens. So we can say the plastic deformation normally happens during this process. Now the slope represents the Young's modulus.

So stress is proportional to the strain so Young modulus can be represented by this stress versus strain, but Young modulus is defined taking into the part of the curve up to that only the linear component from the linear component we can measure the Young modulus the slope actually represents the Young modulus. Then proportional limit of this limit almost in general it is equivalent to the yield point up to that point stress is proportional to the strain.

Then resilience or modulus of resilience that means what is the amount of energy actually absorb during the elastic deformation so up to that point this is elastic so this as a plastic deformation and this is a elastic deformation plastic zone. Now yield strength we define this is the point yield strength just start of the yielding happens at this point so that means just crossing the elastic limit.

And then the start of the yielding process happen that is different by the yield strength. See this yield strength can be as a boundary transition from the elastic to plastic deformation and resilience or modulus of this area we just represents if we calculate the area the amount of the energy actually absorbed between the elastic limit and that energy represented by unit volume.

So this amount of the energy that is represented by the resilience that is called resilience or modulus of resilience and graphically if you have this testing diagram if we simply estimate the area that is the representation of the modulus of resilience. Ultimate tensile strength is the optimum point up to that point we can get the uniform deformation elongation of the sample normally happens and beyond the ultimate tensile strength normally the elongation happens.

So up to this optimum point is called the ultimate tensile strength and further reduction in this thing cross section and there is a non uniform deformation happens beyond that point and at a certain point the fracture happens, fracture happens of the samples. Now in this case the fracture strength is normally estimate what is the total area covered by the up to the fracture point.

What is the amount of the energy absorbed per unit volume that is the representation of the fracture strength? So this is the strength, but this is the from the if you know the fracture point and this strength is the fracture strength, but that area represents the fracture toughness we can say for a particular material. Now offset yield point means in certain material this curve is initial part may not be very prominent as the linear relationship.

So in that cases it is a transition from linear to non linear is sometimes difficult. In that case we define there is a point I think around 0.2% of the strain and that 0.2% strain we can draw the slope of the initial (()) (08:52) = 0 at this point what is the slope we draw in parallel to that slope it cross up to that point. So this point is represented by the yield point in cases which is not having the weld different transition from the linear to the non linear part.

So this is the linear part and it becomes non linear so that transition is when it is not very obvious then we assume the offset yield point and looking into the offset yield point taking the offset yield strain value and accordingly we can decide what is the yield point just looking into what is the amount of the strain 0.2%. Now all this information we can gather from the stress-strain diagram.

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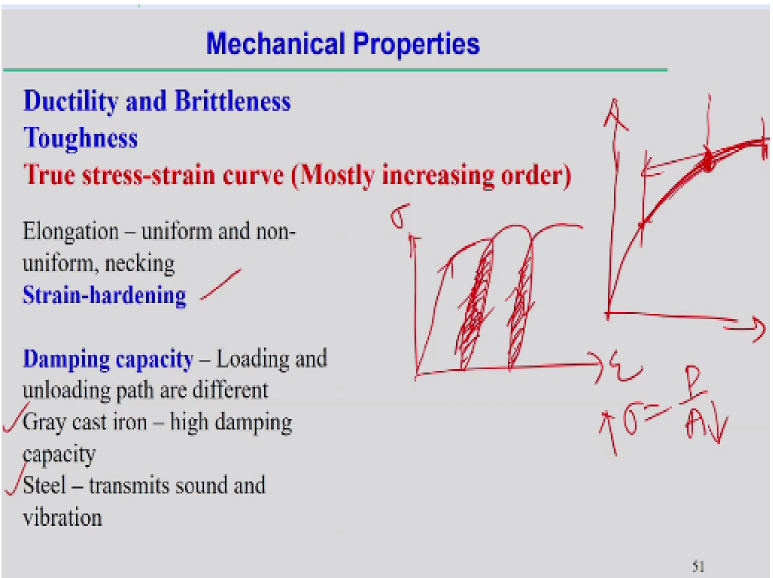

Now the mechanical properties normally evaluate that what is the ductility and brittleness and toughness, normal toughness we have already explained that the area covered up to the fracture point what is the amount of the energy is absorbed that is representation of the toughness of a particular material. Now ductility and brittleness is the measurement of this thing.

Normally we measure the ductility in equivalent to the elongation maybe change of the length with respect to the original length or change of the cross section with respect to the original cross section that is the measure of the ductility and just opposite of ductility that is representation of the brittleness. Normally elongation is more than 5% then we can say it is a ductile it is less than 5% we can say it is a brittle material.

Now once we have engineering stress-strain diagram that means stress/initial cross section area and similarly strain with reference to the initial size that is the engineering stress-strain diagram, but that engineering stress-strain diagram can be compared to the 2 stress-strain diagram. Thus 2 stress-strain diagram is mostly always increasing order. So here yielding point happens and then ultimate tensile strength and fracture strength.

Because in 2 stress-strain diagram we can evaluate we are looking into that particular point what is the instantaneous value of the cross section area and based on that we can divide the stress value. So that is why since further elongation beyond the yield point there is a reduction in the cross section area. So once (()) (11:05) load/cross sectional area so there is a reduction in the cross section area with the same load.

So therefore stress is actually in increasing order so that is why we always get the curve something like a engineering increasing order which is different from the engineering stress-strain diagram. Now this up to that point these are from yield point to that point in the uniform elongation and from ultimate tensile to the fracture point that normally happens the non uniform elongation and the necking starts at this point.

Necking means further there is a further quick reduction of the cross sectional area and at this point so therefore necking starts at this point and just transition point from uniform to non-uniform deformation zone. Then strain hardening parameter also sometimes is represented because the stress hardening is that after yield point there is a material the strain actually increases with the straining of the component.

So in that case since material having some strain hardening effect that means strain hardening effect in further strain the yield point value actually increases the strength level actually increases by straining of a particular component. So that effect is called basically strain hardening. So different material having different kind of strain hardening effect. For example, titanium is having specific titanium alloy is having very low strain hardening effect.

So not much increment with reference to the yield point value with further straining of a sample. So these are the strain hardening properties also we absorbed and then damping capacity is basically if we look into the stress-strain diagram loading the sample in actual cases and then deformation happens then we just released the load and this is the unloading again reloading from this point and this is loading again unloading that kind of behavior.

So therefore it typically follow the loading and unloading part may not be same it depends on the microstructural properties of a particular sample, but if this unloading part and loading part when there is a several loading this area is much high. It means it indicates the damping properties of this particular material is very good. So this area actually if area is more having that means having very good damping properties.

If area is less having less damping properties. For example, it is a gray cast iron having good damping capacity and if we look stress-strain of a gray cast iron with the loading, unloading condition we can get the stress-strain diagram some kind of behavior because gray cast iron this area is more, but in case of steel this area is very less so that means that is why steel cannot absorb the vibrating kind of load that means damping capacity is not good.

So whatsoever with the loading, unloading situation it transmits the sounds and of course it gets the vibration because it cannot absorb the vibration during this process. So that kind of property is also important in certain application.

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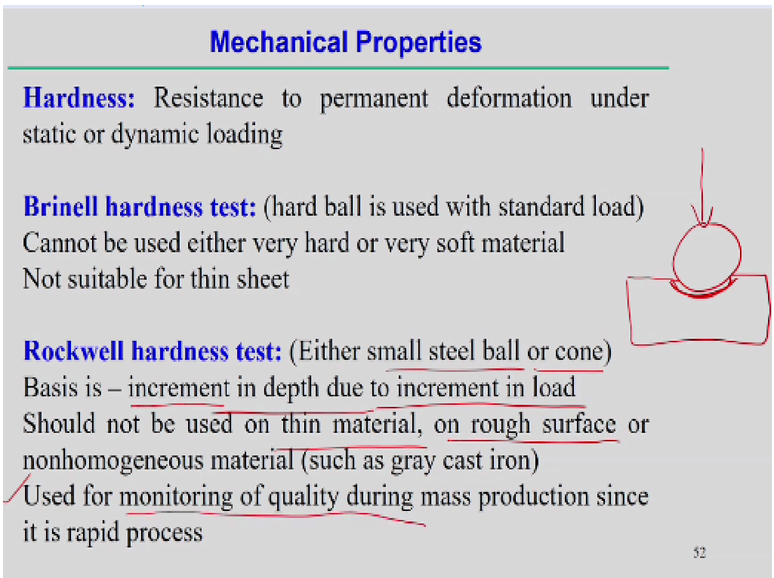

Now hardness also we frequently measure the hardness of particular material that hardness actually represents the resistance to permanent deformation under static or dynamic loading conditions, but there are several methodology or techniques to measure the hardness. One is the Brinell hardness test it is a Brinell hardness test in principle the hardness test we measure in the form with the application of the load.

And with the application of the load and we follow certain indentation and that we measure the indentation it is a particular material and that load/ cross sectional area and that value we can compare with the certain scaling system and based on the scaling we can say we indicate the hardness of a particular material. So but there are different technology basically different methodology to measure the hardness.

So first is the Brinell hardness test in this cases we used the hard ball, hard ball is used with a standard load there is some standard load and cannot be used either very hard or very soft material and of course not suitable for the very thin sheet. So Brinell hardness test use the round shape ball and that ball standard load is applied to this ball and ball actually indent to the surface and we measure what is the indentation area.

And that indentation area load/ indentation area in general that is a representation that is equivalent to the representation of the hardness. Now this Brinell hardness test is normally it is not applicable even material is very soft and at the same time it is not applicable it is not very hard and of course for very thin sheet this hardness measurement technique is not suitable.

We can look into the other hardness testing also testing method. For example, Rockwell hardness test in this cases we can use either very small steel ball or cone, cone type because we ensure with the even application of the small load some indentation it will create. So basis is the increment, but we use this thing and in this cases does not directly measure what is the absolute value of indentation application rather changing the load.

What is the increment of the indentation due to increment of the load? So here we use the increment of the depth with the increment of the load that we can measure it and then we can correlate in the hardness scale and then we represent the hardness. So therefore this should not be used on very thin material of course this is not very suitable on very rough surfaces or of course it is not very suitable in non homogeneous material.

Because the result is very much sensitive to the homogeneity of the structure and it depends on the roughness of a particular material. So therefore this material is not suitable and because in this cases maybe indentation with change in the load the depth of the indentation vary maybe very small, but we detect that depth with this changing of the load and therefore this is used for actually this is very quick method.

And it is very used for monitoring of the quality during the mass products and system. This process is more suitable to measure the hardness and because it is very rapid process.

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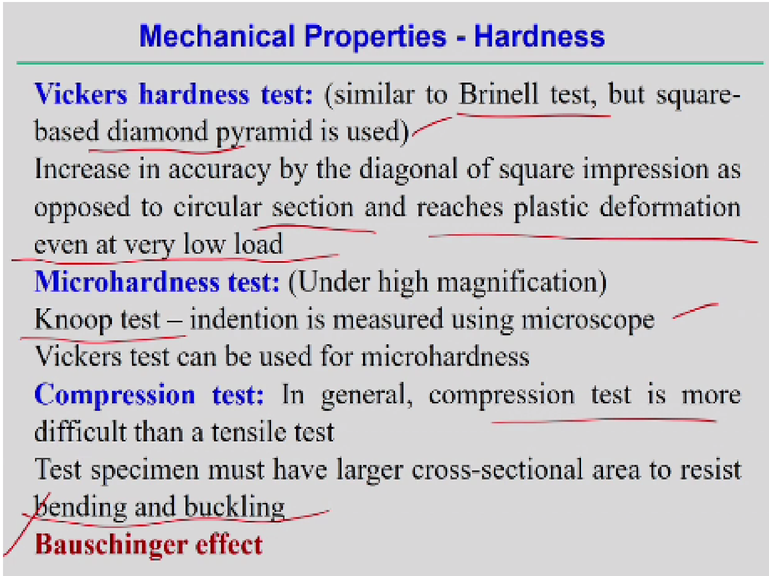

We can see also the Vickers hardness test it is also similar to the Brinell test, but square based diamond pyramid is used. Here we use the square based diamond pyramid, but in this cases the increase in accuracy by the diagonal of the square impression. So presence of the diagonal of the square impression as compared to the round steel ball the indentation can be done or depth of indentation can be increased.

So that is why it is more accurate method and of course as compared to the circular section and of course it reaches the plastic deformation even at very low even load is very small then at least we reach some kind of the plastic deformation and that is the principle it is same to Brinell test, but instead of the round ball we can use the square based diamond pyramid in this cases it is used.

Then several Microhardness testing, but microhardness testing is very small amount of the load is used and of course it is normally happens under the microscope under high magnification. So we observe under high magnification what is the indentation. So one is this the knoop test indentation is measured using the microscope of course. Vickers test can also be used for microhardness measurement.

Apart from that this hardness measurement and of course compression test can also be done we have discussed the tensile testing of a specimen, but at the same time in certain cases compression test is also important and of course combination of the tensile testing and compression testing is also significant to finding out the Bauschinger effect of a particular material behavior.

So in general the compression test is more difficult than a tensile test and of course because test specimen must have a large cross sectional area as compared to the tensile testing and this large cross sectional area required because to resist the bending and buckling during this process. So definitely the compression test maybe significant when we try to look into the Bauschinger effect of a particular material.

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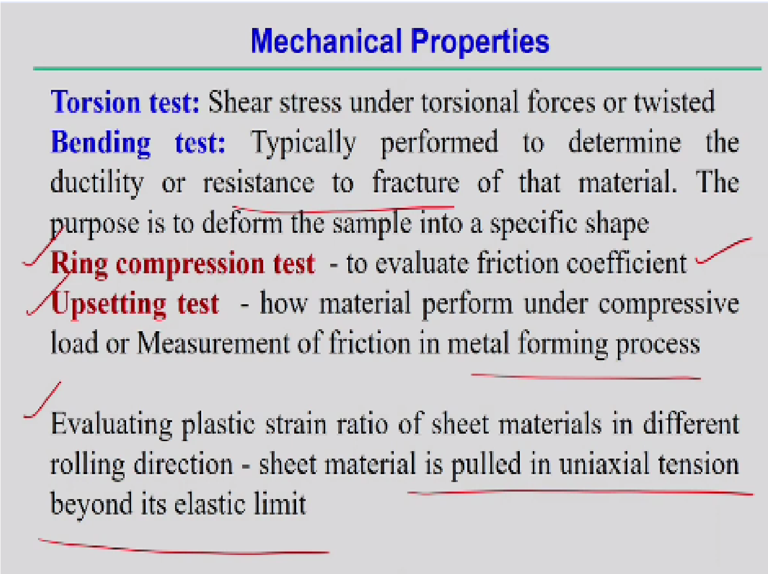

Then torsion test similar kind of normal stress and stress we can that kind of graph we found out from the tensile testing specimen, but if we conduct the torsion test we can find out the relation between the shear stress and shear strength and of course in this cases the torsional load or twisted torsional forces is normally apply to find in case of the torsion test. Then bending test also typically perform to determine the ductility or resistance to fracture or the particular material we can conduct the bending test also.

The purpose is to deform the sample into a bending test is performed to test whether this sample can be deform a particular shape and there are several other methodology for example in mechanically apart from all this standard tensile testing compression torsion and bending testing there are also ring compression test one of the testing method to evaluate the friction coefficients course.

And then upsetting test also can also be done and how material perform under compressive load or this can be used for the measurement of the friction and specifically in case of metal forming processes. So both ring compression test, upsetting test normally associated with the metal forming processes to evaluate the coefficients of the friction of a particular material. Then apart from that evaluating the plastic strain ratio of sheet material in different rolling direction.

That is also that type of property sometime you need to evaluate which is relevant to the metal forming process and basically sheet metal forming process. So at different directions plastic strain ratio because the sheet metal is pulled in uniaxial tension beyond its elastic limit and we can at different direction we can find out the strain ratio in a particular direction which is very important parameter in case of sheet metal forming process.

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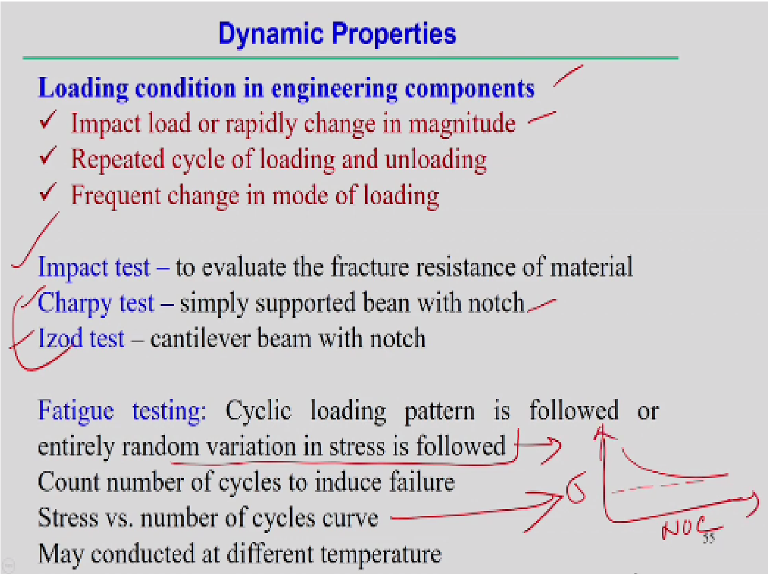

Then with the static loading conditions we can do (()) (21:45) all the properties even from the if it is a dynamic properties can also be measure or mainly the application of the dynamic load. We can use the loading condition in the first of course what way first thing is the if we test any sample in the dynamic loading condition, but first point is that what way we can represent the dynamic loading conditions.

One is the maybe impact load or rapidly change that impact load or maybe load apply in such a there is rapidly change in the magnitude quickly there is a change in the magnitude that is one case. Second case is the either repeated cycle of loading and unloading. So repeated cycle in loading and unloading in the sense we are applying the load and then after half cycle just releasing the load or frequency change in the mode of loading.

That means we are applying the tensile loading and then next half cycle with happening the compressive loading. So like there is a change tensile compressive this type of loading condition. So in practical applications or material may be subjected all this kind of the dynamic loading situation, but if that is the dynamic loading what are the testing methodology we can evaluate the properties of a particular engineer material or manufacture component

First is that to evaluate the dynamic loading condition the impact test can be done, the impact test the purpose of the impact test is to evaluate the fracture resistance of a particular material. So simply impact load is applied for particular material and then material fracture. Then what is the energy of the what is the amount of the energy absorbed to fracture that particular material that we normally measure in the impact testing methodology.

So there are 2 test methodology standard that is a Charpy test and Izod test. Charpy test we use the simply supported bean of that particular material and we make a notch to ensure the fracture happens in a particular notch. So that in that case that is the Charpy test and Izod test of course the similar kind of material can be made also in the form of cantilever beam along with a notch both are impact testing methodology.

Then of course apart from that impact testing the fatigue testing can also be done because fatigue testing normally done by the application of the cyclic loading pattern which is followed either entirely random variation in stress basically we need to when there is a cyclic loading or dynamic loading condition we need to find out the pattern of how there is a variation of the stress when we apply to the sample or specimen.

So with this model first the variation of the stress how it is done and with this particular mode of the loading condition is applied to the samples and then we count what is the total number of cycles to introduce or induce the failure. So therefore we normally plot the curve that a number of cycles this is the number of cycles and along with the stress value corresponding stress value.

And then we can find out that when there are certain number may be in most of the cases infinite number of cycles which is represented around 10 to the power 8 cycles. What is the value of the strength and that we can say this is the fatigue strength of course this fatigue strength is less than that of the yield strength of a particular material because yield strength we can measure under static loading conditions.

So therefore stress versus number of cycles we normally evaluate from the fatigue testing and of course this fatigue strength is also important in other parameter that is at which temperature we are conducting this test. So at different temperature this curve will be different so that as a function of temperature we can induce this fatigue testing also and finally we will try to find out this number of cycles versus the stress curve.

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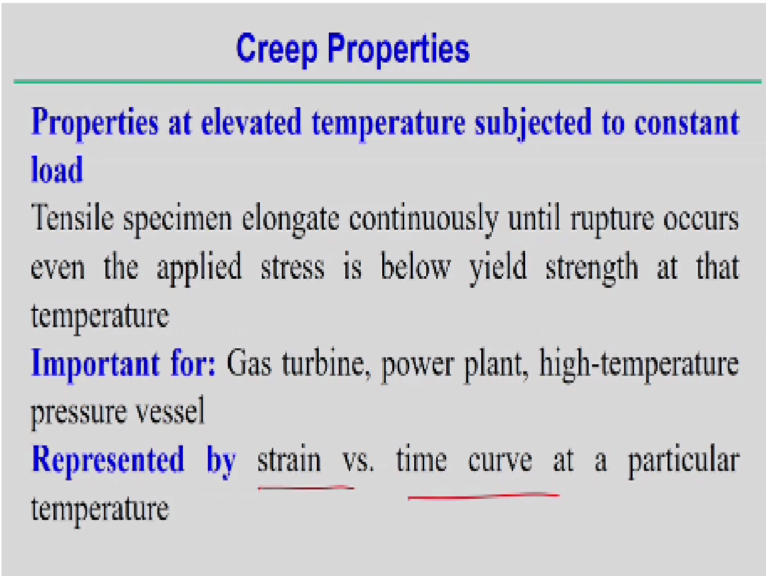

And then apart from the fatigue loading there is another type of loading that is a creep properties we have already mentioned the creep properties is a simply properties at elevated temperature with the application of some kind of constant load how material behaves in that situation. So therefore in this at a particular temperature when you apply some constant load the tensile specimen actually elongate.

And that we are trying to measure this elongation and until this elongation happens until the rupture of the surface occurs and of course this also failure happens below the yield strength value of a particular material. So therefore this creep properties is more significant for the design of a material process for example which is mainly applicable for gas turbine because gas turbine (()) (26:08) in power plant and high temperature application or high temperature application means high temperature pressure vessel.

In that particular cases this creep evaluation of the creep properties is very much significant. It may not be the important when we performance of a engineering particular material at a room temperature value. So therefore they are represented by the strain versus time curve and of course this at a particular temperature we conduct the experiment with a close chamber may be as a particular temperature keep as a particular temperature.

Then we apply the application of the constant load and then we use which is represented by the what is a strain particular strain means particular deformation in the form of particular time. So that output is important to evaluate the creep properties of a particular material.

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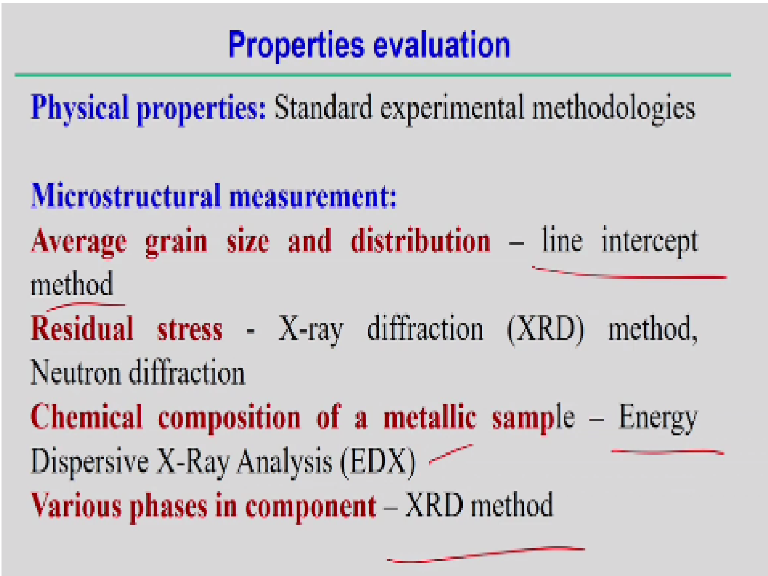

So apart from the other properties the physical properties we already discussed the other physical properties the thermal conductivity for example density that normally use the standard experimental methodology so that is not having the scope of discussion what are the standard methodology, but rather after engineer products what are in general in common we do, we conduct the experiments for a manufacture component.

Next we can apart from this mechanical properties evaluation microstructural measurement can also be done to some extent for example average grain size of a particular microstructure and their distribution is also important. So that is we can use the optical microscope to measure the average grain size or distribution of the grains, but the methodology is used normally for average grain size that is called the line intercept method.

We simply draw a line and this we count this line how many number of grains boundary it cross and based on that we can measure what is the average grain size using this methodology. So apart from that residual stress in most of the cases manufacture component which is a when there is during manufacturing process normally is associated with either purely thermal condition or thermo mechanical conditions.

When the material is subjected to some kind of thermo mechanical conditions then there must be some amount of the residual stress generation so that residual stress measurement also one important aspect in manufacturing technology also. So normally we can use the x-ray diffraction methodology to measure the residual stress of a manufacture component, but this x-ray method XRD method normally use to measure residual stress, particular surface.

If you want to measure the interior, then x-ray may not be suitable in that cases so in that case neutron diffraction technique is the more suitable technology even we can measure the residual stress along a particular depth direction of a manufacture component. Apart from that chemical composition often we used for a metallic sample we can use the energy dispersive x-ray analysis EDX process can also be used for analysis of the chemical composition.

And of course various phases of the component we want to measure in a sample then we can use the XRD method also. So all this microstructural measurement may be associated with the manufacture component to analyze or performance of a particular component.

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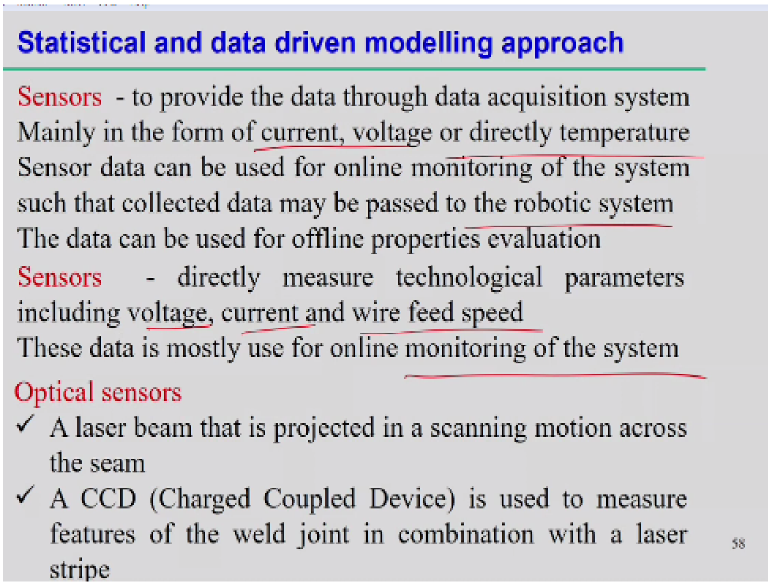

Now apart from that statistic the properties evaluation this thing I am just shifting to the next module the next part that is the statistical and data driven modeling approach. So once we go for some kind of modeling approach mathematical model what we can dealing with the statistical data without looking into the physical aspect of a particular process. So in that cases if we have the data.

Then we can analyze the data by following some kind of the statistical and data driven modeling approach, but before that the point is that whatever we can evaluate we can extract the data which is maybe that data can be extracted may be to evaluate the properties of a manufacture component or the data can be evaluated during the manufacturing process to simply either monitor the process online or may be it can be done offline monitoring of the process.

But if you want to collect the data during the manufacturing process then we need to use some kind of the sensor. So sensor is to provide the data through some data acquisition system and that sensor gives the output mainly in the form of the current voltage or maybe directly temperature can be measured also. So therefore the sensor that are mostly used for online monitoring of the system.

And that can be collected, data may be passed through the robotic system if we use because when we do look into the monitoring system then data is passed to the robotic system and thus robotic system that robot can monitor the process. So therefore, but that is the robotic process how it evolves that is not the point of discussion but discussion what we can collect the data and how we can utilize the data.

So sensor directly measure the technological parameters or normally including the voltage, current and may be wire feed speed in cases in case of welding process also we can directly use the wire feed speed. So this data mostly used for the online monitoring of a particular system, but apart from the sensor data this output in terms of the voltage and current. So optical sensor can also be used.

And in that cases we can use the laser also, laser system the laser beam is used and that projected the scanning motion across the particular seam we can project the laser and then this reflected data information can be capture by the CCD is used to feature of the weld joint in combination with a laser stripe. So point is that laser based sensor also available for online monitoring of the system.

And of course sometimes the CCD system can also be used to extract the data during the manufacturing process.

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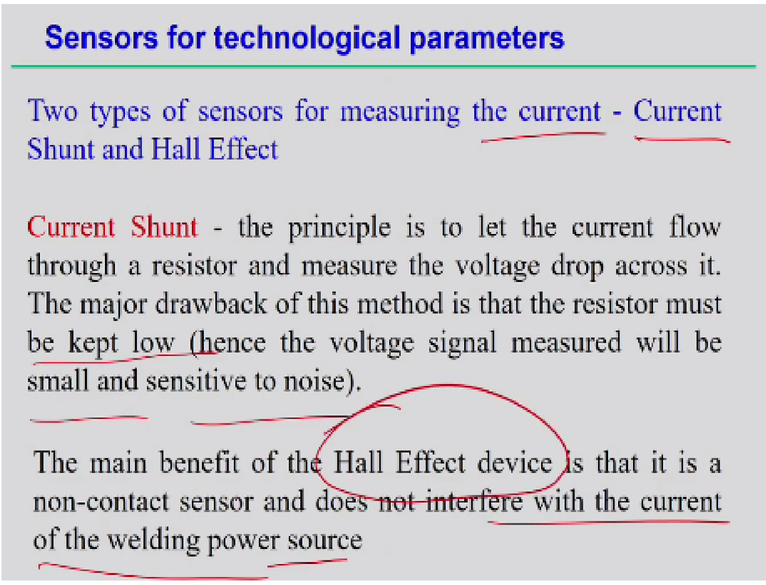

Now 2 types of the sensor for measuring normally used for measuring the current and of course that for measuring the current that is called Current Shunt and the Hall Effect. So Current Shunt Effect this principle is that suppose let the current flow through a resistor and then measure the voltage drop across it, but the major drawback of this process is the resistor must be kept low.

So therefore the voltage signal measured will be small and sensitive to a particular noise, but this is the Current Shunt matter because we follow some kind of the parallel system, but in case of the Hall Effect devising such that it is basically non contact sensor and does not interfere with the current of the welding power source. So that means if we use the welding system then it does not interfere the welding power source so in that way you can use.

So if you want to measure of a particular manufacturing process, manufacturing system they are probably in that cases we normally use the device Hall Effect to measure the current flow.

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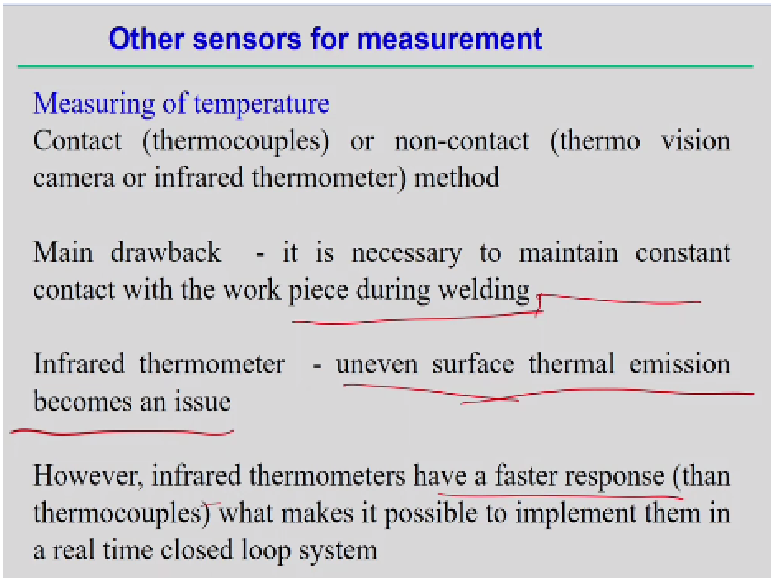

Then other sensor of the measurement maybe most of the manufacturing process may be associated with the measurement of the temperature. So in that cases mostly used the thermocouple or may be non contact may be thermal vision camera or infrared thermometer can be used to measure the temperature, but main drawback is necessary to maintain the constant contact with the work piece during the welding process.

So that means during the welding process or any other manufacturing process if you want to use the contact mode that means of measuring that means if you simply the thermocouple then always we need to contact with the sample. Other is the infrared thermometer of course it is not necessary to directly contact this is a non contact mode we can measure, but (()) (34:04) to that uneven surface there if basically detects the thermal emissions from the surface.

So therefore on thermal emission is not proper then it is very difficult to detect based on the non contact mode using the infrared thermometer or thermal vision camera. So therefore, but till if we compare the thermocouple based and infrared camera to measure the temperature that thermocouple if you want to monitor the system then thermocouple data is not suitable rather the infrared camera measure is a more that data normally we can use.

Because there are some response time when you measure the temperature using the thermocouple. So that responding is quickly the response time is little bit more or it can be delayed in the monitoring system. So therefore the infrared thermometer have a faster response so it is more preferable to use for online monitoring of the system through which we can measure the temperature.

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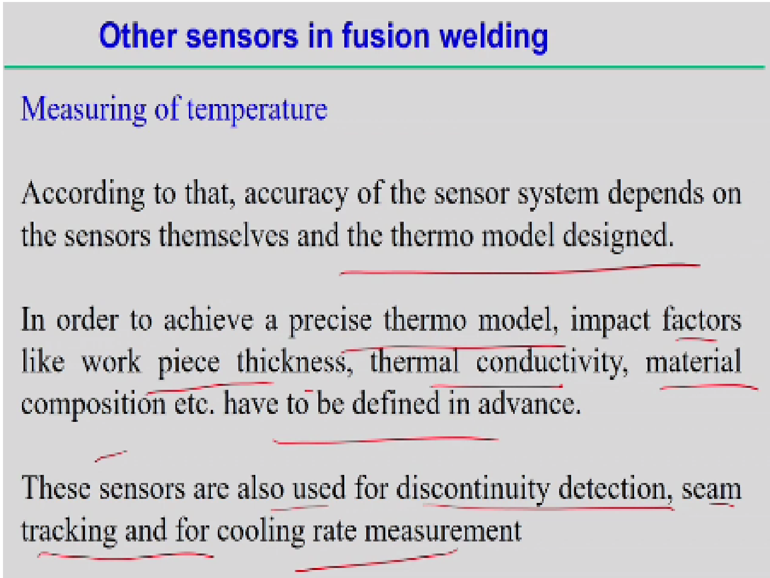

So therefore according to the accuracy of the sensor system depends on the sensors themselves and of course thermo model designed that means we are capturing the data, but how we can convert the this thermal image in the form of a temperature. So that need some kind of the design that kind of model is required. So therefore in order to achieve precise thermal model impacts factors like the work piece thickness, thermal conductivity, material composition etcetera something have to be defined in advance.

And accordingly we can make the model such that we can correctly measure the temperature by looking into all this factors. So these sensor are also used for discontinuity detection, seam tracking and cooling rate measurement as well also. So therefore all this sensor data can be analyzed such that we can measure the discontinuous during the process if the discontinuity happens then we can detect by this temperature also.

And of course what is the cooling rate from the temperature measure then that can also be measured when you try to measure the temperature.

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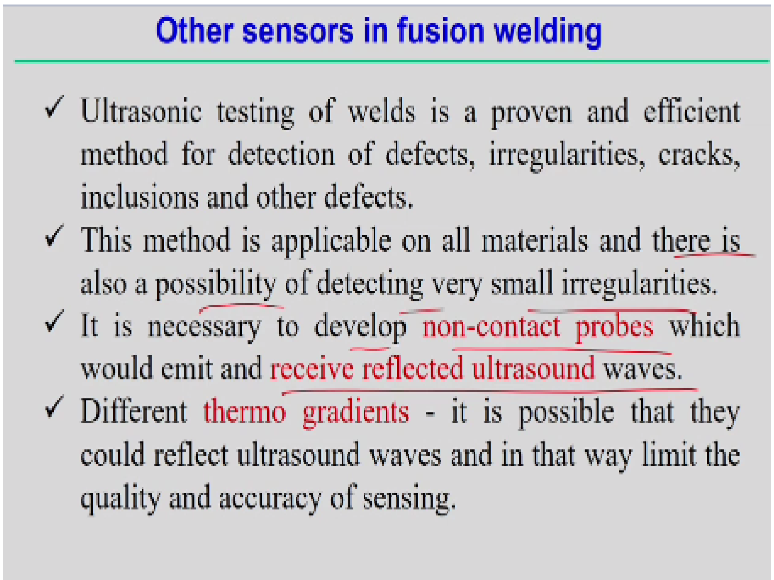

Now other sensor in fusion welding process we normally use that ultrasonic or not only fusion welding in other processes also we can use the other type of the sensor. One is the ultrasonic testing of welds as one of the efficient method for the detection of the defects, irregularities, cracks, inclusion and other surface defects one is the most proven technology is the ultrasonic method.

So this ultrasonic method actually applicable for all type of the materials, but there is also a possibility of detecting very small irregularity that is another advantage using this thing by looking into the pattern of this ultrasound. So therefore delay, non-contact probe which is used and actually that is reflected ultrasound so we detect first we pass the ultrasound then there is a receiver that reflected ultrasound waves are detected by the receiver and we analyze this ultrasound pattern.

And based on that we can detect the defect or other irregularities or process even it is possible to their existence of thermal gradient also in the material during the manufacturing process or after the manufacturing process the thermal gradient can also be possible to detect through the ultrasonic testing technology.

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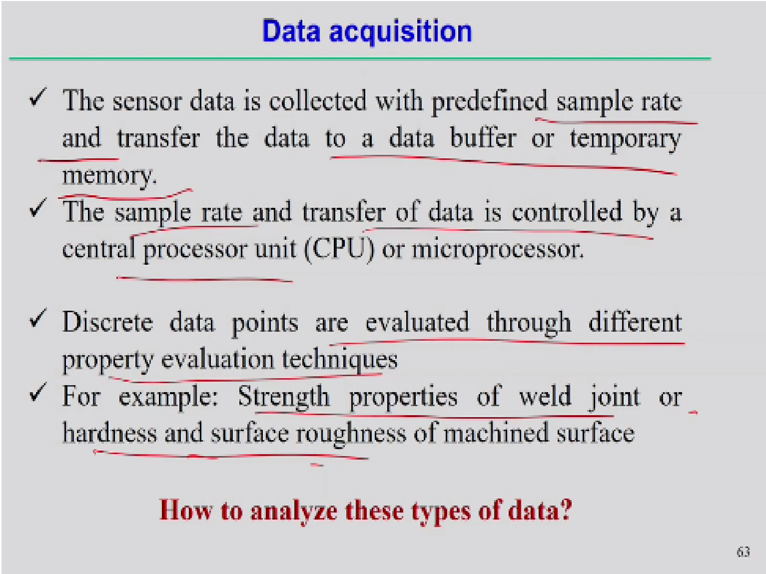

Data acquisition then once we use different types of the sensor and to collect the data and of course this data acquisition system can also be done once we do after the manufacture component even if we do the testing from the testing result we can collect the data. For example if you do the tensile testing of a manufacturing component of the different parameters then we can get the data like tensile strength, elongation, ultimate tensile strength, yield strength all kind of data can be evaluated from those things or other way.

If we use some monitoring system we can acquire the continuous data, but the data is collected in that continuous data during the manufacturing process from the sensor the data is collected some predefined sample rate so that means with the gap with certain frequency we collect the data and that data normally store in the temporary memory or maybe that is normally data acquisition system through the data acquisition system we can collect the data.

And that the sample rate and the transfer of the data is normally controlled by the CPU monitor or through the microprocessor we can control the data acquisition system, but we use the data continuous data and we can analyze the data also. Apart from this continuous data some discrete data point can be evaluated through different property evaluation techniques of different experimental techniques also.

For example, strength properties of weld joint or hardness surface, roughness or machined surface can also be collected measurement these are the typical data we collect. Now point is that different processes either monitoring processes or offline monitoring process that means if you do some testing of the sample and stretching of manufacturing components we collect all the data now point is that what we can analyze this data.

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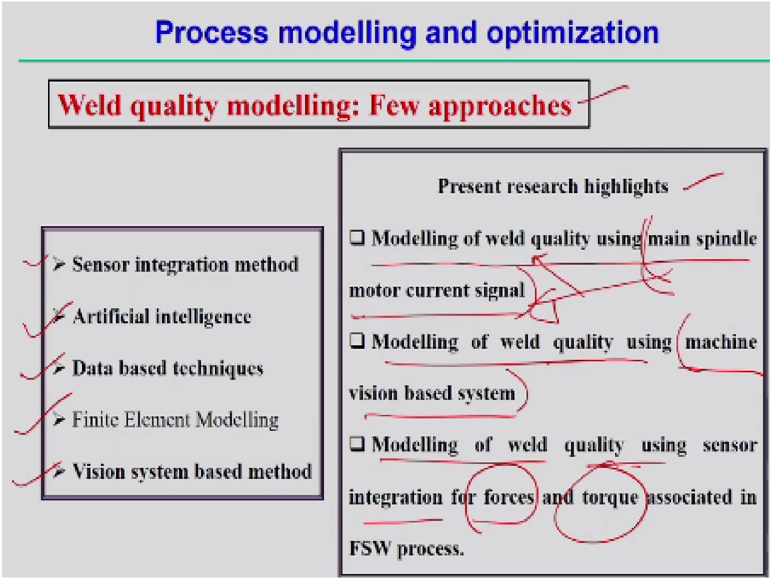

So that data analyze there are several that is called the process modeling or we can say the mathematical modeling of the manufacturing process, but this mathematical modeling is completely different from the physics based, mathematical modeling approach. Here we will be dealing only this kind of modeling we will be dealing only the data, only data value without looking the physics involved during the manufacturing process.

So for example we can take one example say weld quality modeling so few approaches in weld quality modeling. So there are several method what is the sensor integration method so what way we can integrate the different sensor data that is one methodology then artificial intelligence we can apply to find out some parameters then data based different database techniques about analysis of the data and different statistical correlation is also possible if you analyze the data.

And of course finite element modeling while finite element modeling is the different these are physic based modeling approach. This is a tool we used to model the manufacturing processes and of course apart from this data and if we use the data image capture the image and if you analyze the image then vision based system method can also be developed. So these are typical methodology for weld quality monitoring normally follow in case of type of friction stir welding process.

So recently we are working in that area the present research highlight for example we are trying to do the modeling of the weld quality using the main spindle motor current signal. So basically this is the data main spindle motor current signal in case of friction stir welding process so this data is collected by putting some kind of sensor and that is from the center we can collect.

And then this data can be related with a weld quality, quality of the weld joint in terms of the strength or of course modeling of the weld quality using the machine vision system. This machine vision system is basically we capture the image during the process so we analyze the image and that particular image analysis we just try to link with the weld quality using following some kind of the data driven modeling approach.

Then modeling of the weld quality using the sensor integration for force that means from force sensor force measurement and from the torque we can measure force and torque during the process and we can link this force and torque with the we can model it in the sense that we just try to find out the correlation with respect to the input parameters in specific to the friction stir welding process. This is just typical example of the data driven modeling approach.

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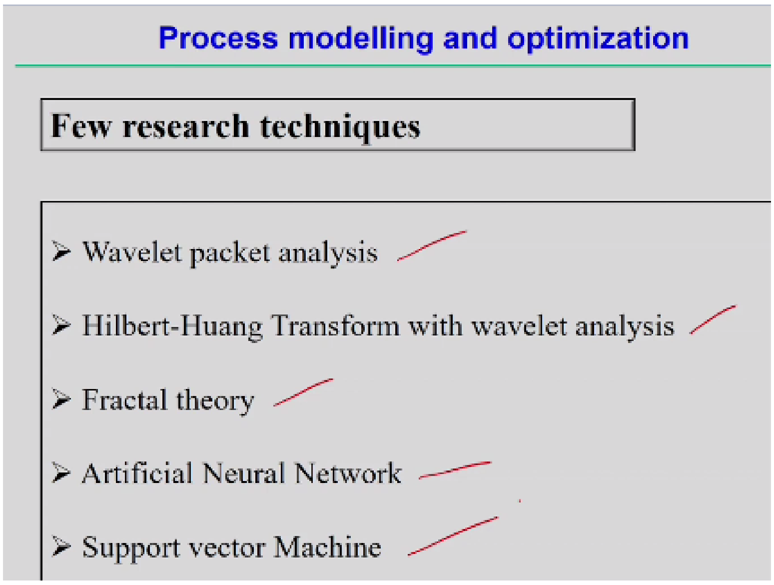

Now few research techniques, techniques of the modeling approach we can use the wavelet packet analysis the standard packet available in the standard software also a wavelet packet analysis then Hilbert Huang Transform with the wavelet analysis so along with the one derivation from the wavelet analysis for a data driven modeling approach. Then we can use the fractal theory to characterize the signals by estimating what is the fractal dimension for a particular signal.

Signal means is basically sensor data so that correlation can also be possible to explain using the application of the fractal theory. Similarly, neutral network model can also be used, what is the input we decide the input parameters and in between we correlate the output parameters and even we can predict some data or relate between by looking into the relation between the input and output parameters.

Similarly support vector machine can also be one of the methodology to represent the two, define or to express the weld quality, welding quality in case of the mathematical modeling approach.

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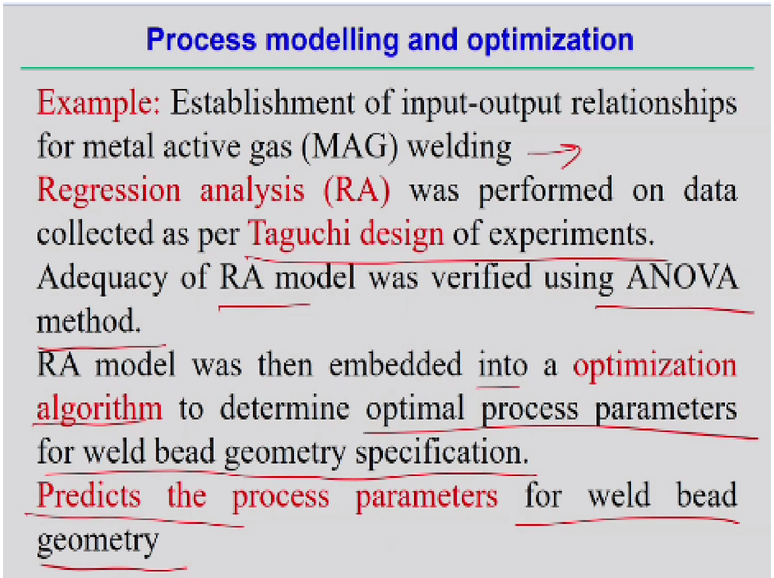

So once we look into that collect all the data and different techniques, but if you look into the overall view how we can do the process modeling and specific even we have lot of data, but and whatever we can do the process modeling and whatever we can optimize this process parameters or we can look into one example. For example, the establishment of the input-output relationship.

For example, metal active gas welding process. So in this cases there are so many inputs for example the current voltage and feed rate of the wire that can be the input to the process and output may be strength, maybe some other parameters, strength or maybe weld bead dimension maybe the output of this things, but we can relate always interested to relate between the input and the output parameters.

Now what are the process we can use, we can use the simple regression analysis and that regression analysis which was performed on the data, data actually collected by following (()) (44:35) design of experiments the following certain norms of the experiments and of course this regression analysis is simply relate between the input parameters and what is the output and that correlation.

And of course the adequacy of the regression analysis model is basically the feasibility of this model parameters all this thing analysis is normally using the ANOVA method, the standard method available all the statistical information will be available using if we apply some ANOVA techniques. So then RA model was then regression analysis is basically embedded into an optimization algorithm.

So this RA model is simply the relationship between the input and output that can be integrated with some optimization algorithm to determine the optimal process parameters for weld bead geometry specification that means if we know what is the relation between the input parameters for a particular welding process the current voltage and this feed rate and what is the output parameters this things by using this relation.

Now we can optimize suppose we are looking for a desire weld dimension we want to get this dimension. Therefore, we utilize the relation between input and output through regression model analysis and then if this is the desired input and output and then we passes through optimal algorithm such that this for particular to get the particular weld dimension we expect what should be the input parameters for this cases.

So normally done by integrating the optimization algorithm. So therefore if we integrate with the optimization algorithm that predicts the process parameters for the weld bead geometry looking for a particular weld bead geometry then we can find out what should be the input parameters for a particular welding process, but with the help of the optimization algorithm and of course before doing that we need to establish the relation between input and output through the regression model. So regression maybe linear or the relation can be non linear also.

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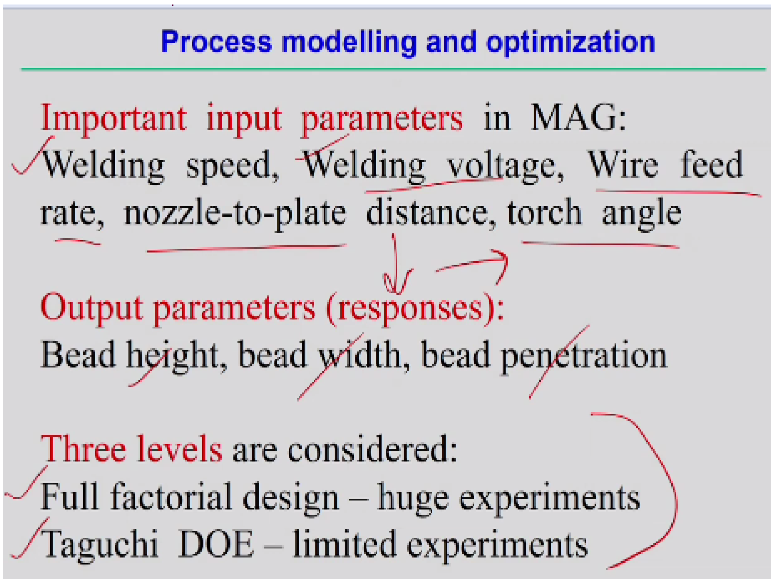

So therefore input parameters of MAG welding process maybe you can say the welding speed, welding voltage maybe another parameter, wire feed rate is another parameter, nozzle-to-plate distance is another parameter and torque these are the all input parameters and now output parameters or responses we can say height, bead width and bead penetration. So height this is the output parameter.

So we get if this is the input for a particular set of the input we can get particular output in the form of the weld bead height and penetration of course so in this cases 3 levels are considered and therefore we can design this in full factorial design if we consider the 3 level of experiments so basically 3 different values of the all the input parameters. Then there is a lot of experiment will be required if you go for the design of experiment for a particular process.

But if you follow the Taguchi design of experiment therefore that suggest some kind of limited number of experiment is actually require so we can reduce the number of experiments in that case. Now point is that if you follow this kind of try to establish the relation between the input and output through some regression or some statistical model between this input and output.

Then in that cases the reliability of this relation will be depend on large number of experiments so therefore in this cases large number of experiments is actually required.

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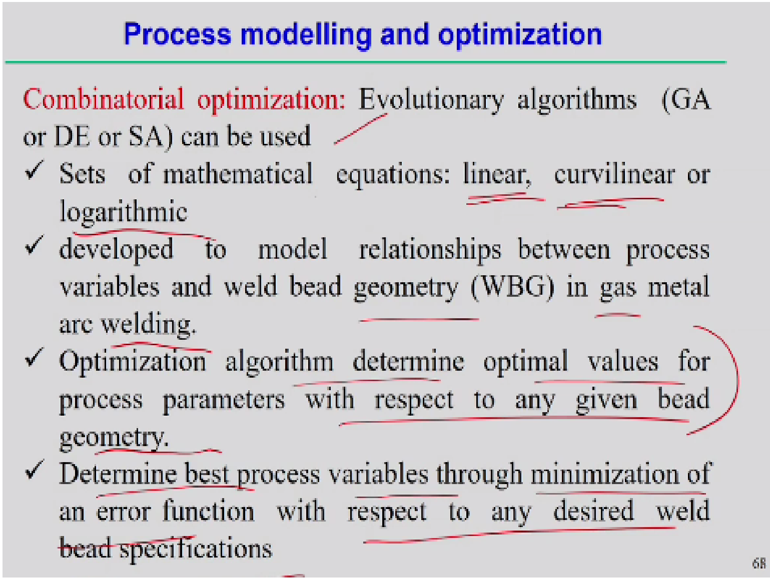

Now if you integrate the optimization algorithm to find out the optimum set of parameters for a desired weld bead geometry desired output then in that cases the optimization algorithm can be used the GA based evolutionary algorithm. GA genetic algorithm differential evolution simulated annealing can also be used and of course in this cases the set of mathematical equations the linear curvilinear or logarithm relation between the input and output is required.

So therefore this relation is developed this relation between the variables and the weld bead geometry and gas metal arc welding process. So therefore this in the form of the linear, curvilinear or logarithm relation can establish between the input and output. Now optimum algorithm determine is the optimum values for the process parameters with respect to any given bead geometry.

So optimum algorithm actually try to decide the range of the parameter and then it checks for a particular set of the input parameters what is output parameter by checking the already established the relation then if output parameter is not desirable in this cases then it test for the next set of population so that way it moves and try to estimate what is the optimum parameter for a particular desire output.

So then determine the best process variable through minimization of the error function with respect to the any desired specification. So now to (()) (49:40) algorithm is calculate the one specific for a particular set of the input it calculate the one particular set of the output then that output is compared with a desire output compare it, create the error and that with over the iteration you try to minimize that error. So that is the overall procedure of the optimization algorithm.

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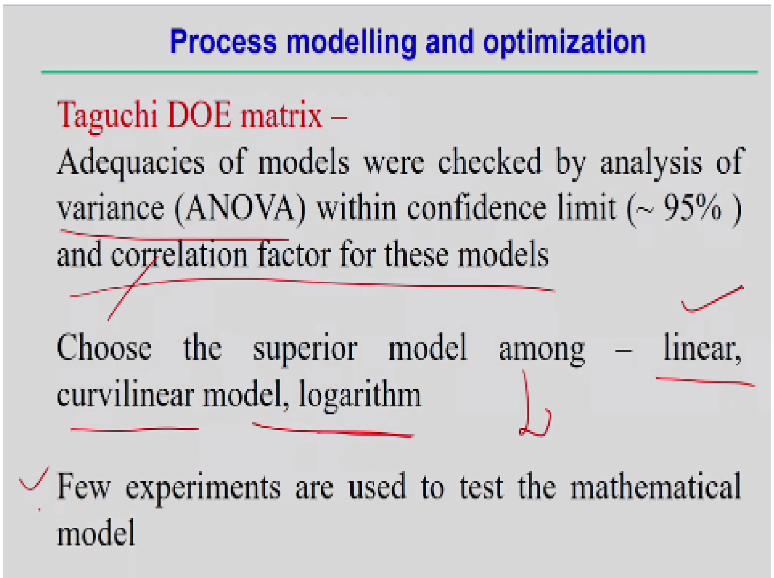

Now Taguchi design of experiment we normally follow that model is checked b the analysis of the ANOVA table normally variance with confidence remains 95% and all the correlation factors among different parameters or set of parameters is tabulated using the standard ANOVA table. Therefore, choose to from this analysis there is a choose maybe one analysis can be done, some linear relationship then choose the superior model among the linear, curvilinear algorithm.

If we start with the input relation between input and output in the linear by using some linear function, (()) (50:39) or we can use some curvilinear model or we can use some logarithm model. So based on the ANOVA table results we can choose which one is the best representation the statistical curve between the input and output parameter. So therefore after that which establish the relation between the input and output parameters.

Then few experiments are needed to test the mathematical model whether it is giving the right output or not so that is why we can validate this relation.

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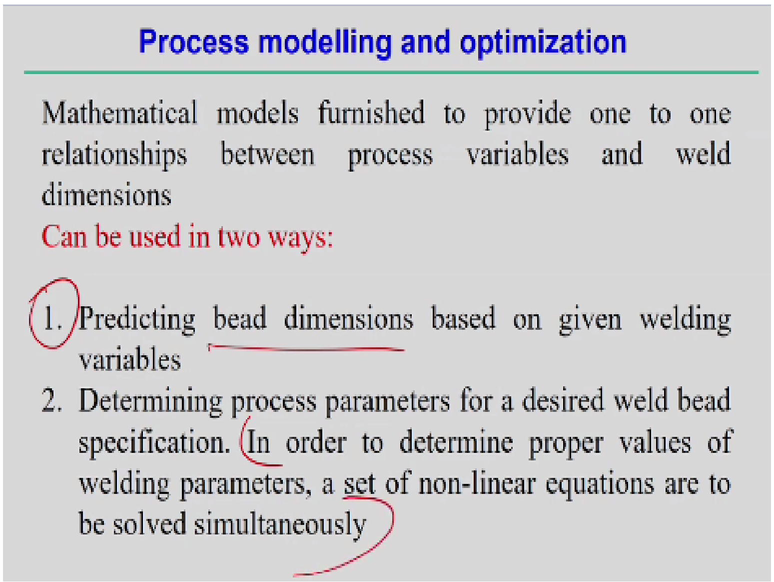

So therefore mathematical models furnished to provide one to one relationship between the process variables and the weld dimension, but can be used in the two ways. One is the already discussed the predicting the bead dimension based on the given welding variables. So we can predict particular dimension using the given variables or with other way also we can determine the reverse things we can find out which is possible to determine the process parameters.

If you want to get a particular weld bead specification. So therefore in order to determine the proper values of the welding parameters a set of non linear equations are to be solved simultaneously and that way that sort when we try into look into this can be performed by integrating it with some optimization algorithm.

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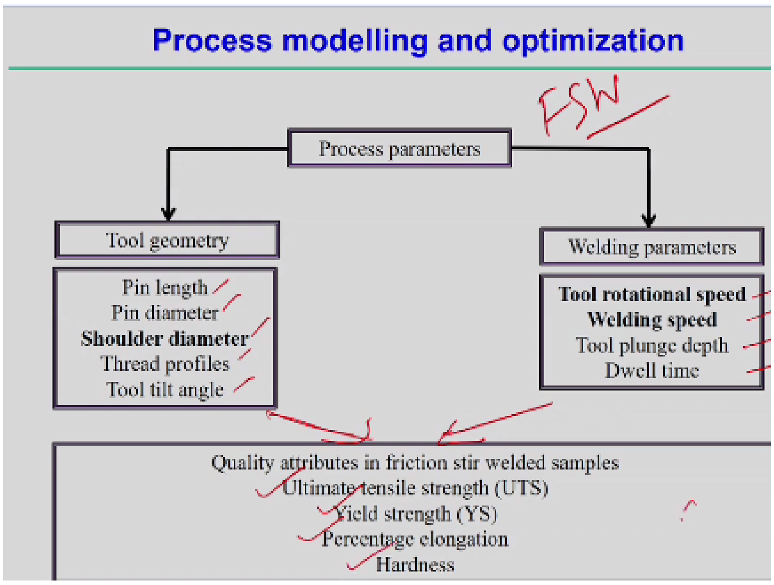

So we can look into that some application of this thing. For example, process parameters in FSW process the tool geometry. Tool geometry there are different types of the pin length, pin diameter, shoulder diameter, threat profile, tool tilt angle all are the parameters which is maybe input parameters tool geometry specification and apart from that tool geometry welding parameters are also responsible. So this is corresponds to (()) (52:19) welding.

Now welding parameters are the tool rotational speed welding speed, tool plunge depth and the dwell time. This are the all the welding parameters. So this all the input parameters. So this input parameters is used to predict either different data driven modeling approach in neural network modeling approach or other statistical approach can be used to predict the ultimate tensile strength of a weld joint, yield strength of a weld joint.

And percentage elongation of a weld joint and what is the hardness of (()) (52:51). So this is the output from the model and this are the (()) (52:56) and this relation is established through some statistical or data driven modeling approach. So this is all about the different parts of the approach normally we follow in the statistical or data driven modeling approach, but this course is not exactly focused on the analysis of the different types of the techniques and data driven modeling approach is used.

Rather I have discussed this point just to know there is other direction of the modeling approach, but our focus will be in the next other modules to look into the physical aspects of the manufacturing process and to explain the different type of the manufacturing process and their modeling approach by looking into the physical phenomena associated with the particular manufacturing process. So thank you for your kind attention.