Basics of Mechanical Engineering-1

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Week 02

Lecture 08

Mechanical Properties – Stress and Strain and Residual Stress

Welcome to the next lecture. Here we will try to cover the Mechanical properties. When we try to see a material, we are supposed to evaluate the material and then see whether it is suitable for the application. For example, we try to use plastic spoons. These plastic spoons are sometimes given by street vendors, in trains, in marriage parties and other occasions.

These plastic spoons have very low stiffness because the vendor tries to optimize the charges by giving you a thin spoon. When he gives a thin spoon and we start eating something, it deflects or it falls down or it trips down or it deforms. Why is all these things happening? Because the material property was not properly judged. And sometimes what we do is we smartly take two spoons and we take two spoons together, tie it up and then start making it use for the application.

While doing so, what did we do is we increased the stiffness of the spoon. Same with ice cream sticks also. So knowingly or unknowingly, we increased a number. Truly what happens to the situation is the material property was not properly analyzed or we had to make sure before choosing a material that we should look for its properties. You might ask a question, when we buy spoon, nobody gives or demonstrates or displays the mechanical property. I understand.

So, then what do we do is, we buy a product and we just try to bend and see whether what is its stiffnesses. The same thing happens when we buy a shoe, when we buy a small toy, when we buy a rubber band, we always see that it has an early failure. The early failure happens because their mechanical properties were not judged before fabricating. Or keeping cost constraints, they would have compromised the mechanical property. Now it is very clear that we should understand the mechanical properties of any given material.

As an engineer, it is a basic thing that mechanical properties of material has to be understood.

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In this lecture, we will try to cover the following topics. Introduction to Mechanical properties. The major properties are Stress and Strain. Then what is their relationship?

How does a stress-strain curve look for a typical material? Sometimes what you do is when you try to bend a material and leave it, after a certain period of time it relaxes. So, what is that is the residual stress.

So, we will see what is residual stress, what are all the causes for residual stress and what is the effect of residual stress in the performance? Then measurement of residual stress, real world application and then recap.

Mechanical Properties

- Mechanical properties are characteristics that describe the behavior of a material under the action of external forces.
- Understanding these properties is crucial for designing and analyzing mechanical systems.

Examples :

- **Elasticity:** The ability of a material to return to its original shape after the removal of a force.
- **Plasticity:** The ability of a material to undergo permanent deformation without breaking.

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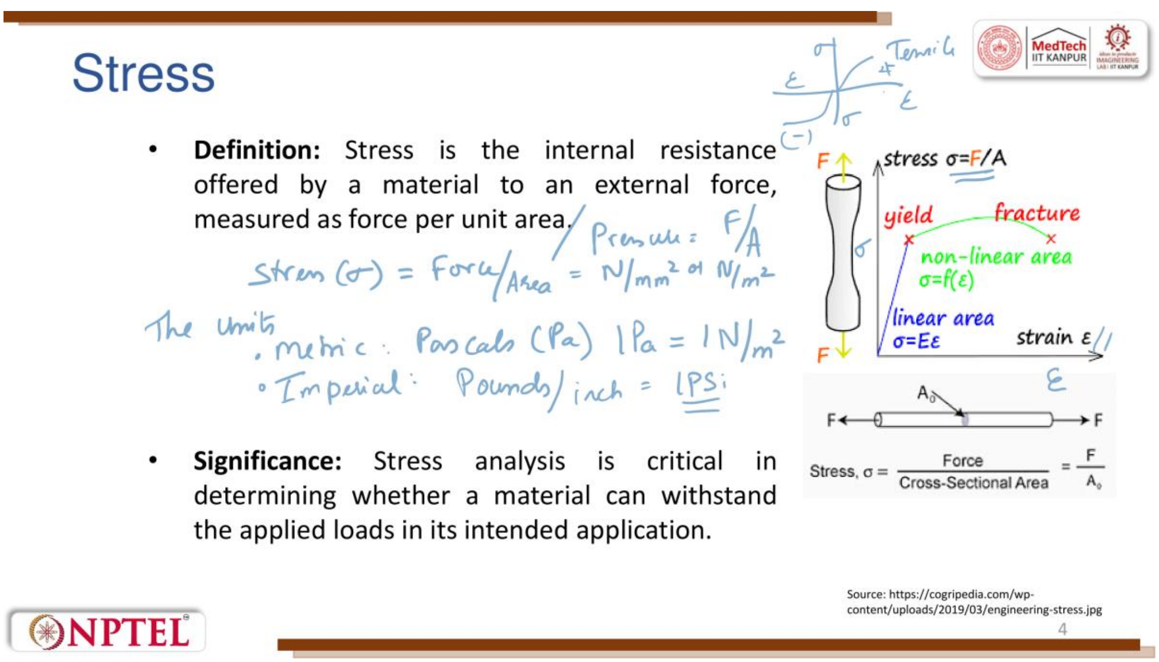
Mechanical properties are characteristics that describe the behavior of a material under the action of external forces. For example, you try to take an object, try to press the object, try to pull the object, try to shear the object. Torsion shear the object, so all these things are external forces and in real time, many a times, there will not be a single force for example, there can be tensile and compression happening together in real world application. There can be compression and shear for example, when you try to take the same object compression, you keep on pressing and suppose you also wanted to rotate, so then shear comes into existence. People say shear and sometimes they also say torsional.

But both are different terminologies. Application wise external force can be shear force or torsional force. Understanding these properties is crucial for designing and analyzing a mechanical system. So, Elasticity and Plasticity are two different properties which is exhibited by almost all materials when we try to do a mechanical testing. Elasticity can be dominant or plasticity can be dominant or elasticity can be very small and plasticity takes everything.

So, the examples are elasticity means the ability of a material to return to its original shape after the removal of force is called as elasticity. For example, you press an eraser and then you release it, it comes up. You press a cushion; you apply a compressive load. Once you release the compressive load, it comes back. So that is called as Elasticity.

Plasticity means you try to poke the same eraser with a pencil. So, after applying a certain force, you have a pierced hole made. Now, that is called as Plasticity. So, you have entered into a zone wherein which you cannot recollect, but it makes a permanent damage. So, plasticity is the ability of a material to undergo permanent deformation without breaking.

Sometimes you will also see your handkerchief or your pant. It would have lost its strength. You can see the fibers, but it would still have a life till it is getting torn. The same way, when you try to hit a nail, many a times you will see the head would have deformed, but still the nail will try to do its job of holding. So next let us try to understand the important two properties. One is Stress, the other one is Strain.



Definition for Stress. Stress is the internal resistance offered by a material to an external force, measured force per unit area. Can you draw an analogy somewhere else? Yes. So, it is $Pressure = \frac{F}{A}$.

$$Stress\ (\sigma) = \frac{Force}{Area} = \frac{N}{mm^2}\ or\ \frac{N}{m^2}$$

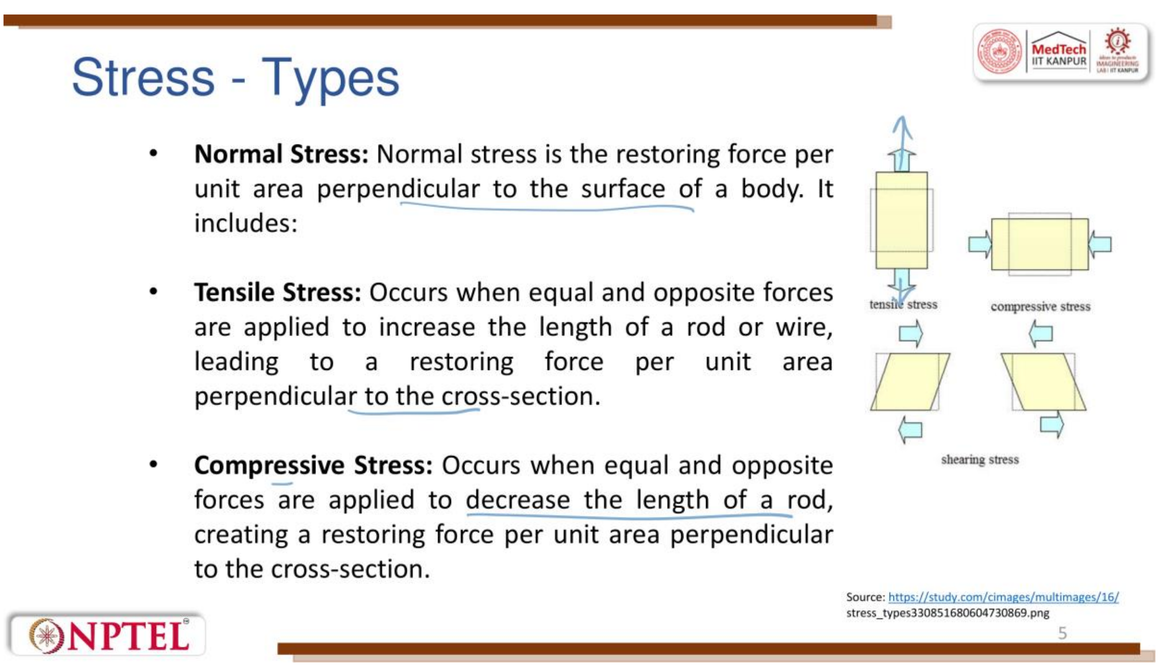
$$Metric: Pascals (Pa) 1Pa = 1N/m^2$$

$$Imperial{:}\frac{Pounds}{inch} = LPS$$

In imperial, we use pound per square inch which is nothing but 1 psi. So, this is what is used in your tires. So, if you see here generally when the material is tested, it will be plotted against stress versus strain. So, this becomes stress and this becomes strain. So, it is force per unit area strain, we will see it is a dimensionless quantity.

So, when we apply force, so here it is tensile, you can also apply compressive force. The only thing is what will happen is in the 4 quadrants, so your tensile will plot it here and compression we will plot it here. Again, this will be strain and this will be stress. So, we can try to say this is negative and this is positive will be similar, but if you do in a microscopic level, you will see lot of difference. But by and large, it will have a linear and a plastic region.

The significance of stress analysis is critical in determining whether a material can withstand the applied load in its intended application. For example, you try to briar spring. So, what is the maximum kg it can hold or what is the maximum strength when we try to put a spring between two points and then you keep on repeatedly doing an operation how many cycles it will withstand. So, it is always necessary to first start understanding the material property. So, stress is defined as force per unit area which is P by A naught.

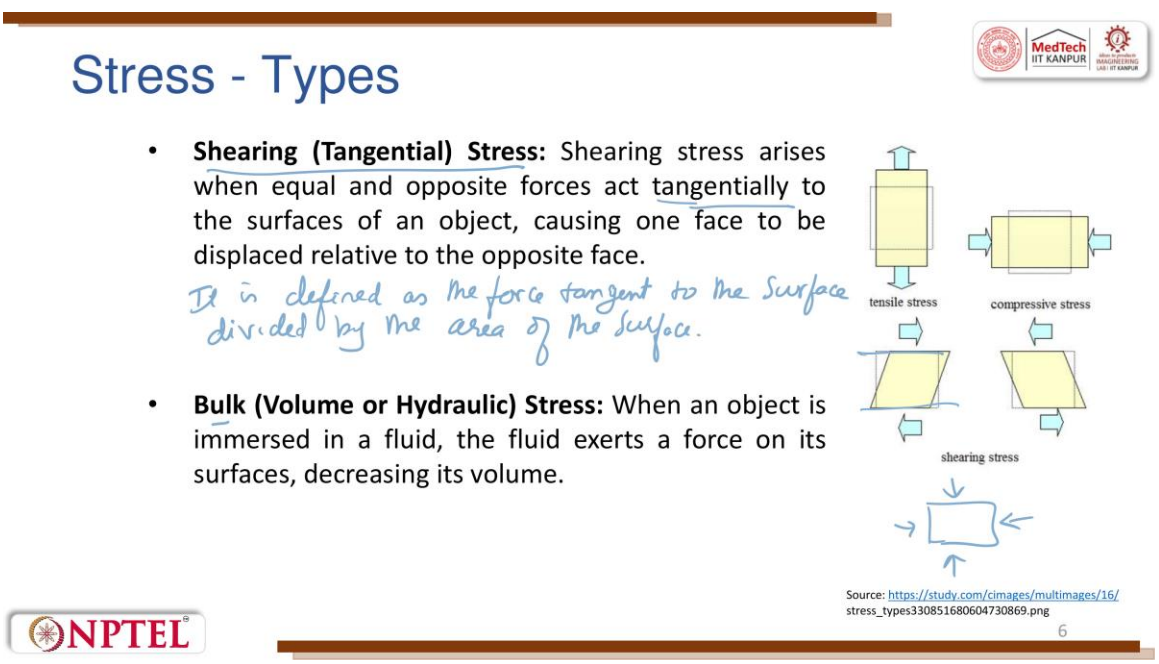


Stress types. There is a normal stress which includes tensile and compressive. Normal stress is the restoration force per unit area which is perpendicular to the surface of the body. So, it includes tensile stress. Tensile is you have an object; you try to pull in both directions. For example, you try to have a spring and try to pull the spring that is tensile.

Or you try to hang, in the sense you try to hold yourself while doing gym experiments, you try to gym exercise, you try to hold your body to a hook, and then you do vertical push-ups. So, here it is tensile. So, when you sit on a chair, it is compression. When you stand on a floor, it is compression. When a camera stands on the floor, it is compression. Right.

So, tensile compression occurs when equal and opposite forces are applied to increase the length of the rod or a wire leading to the restoration force per unit area perpendicular to the cross section. So that is called as Tensile stress. Compressive stress occurs when equal and opposite force are applied to decrease the length of the rod. For example, you have an eraser. I gave you an example. You have another soft material.

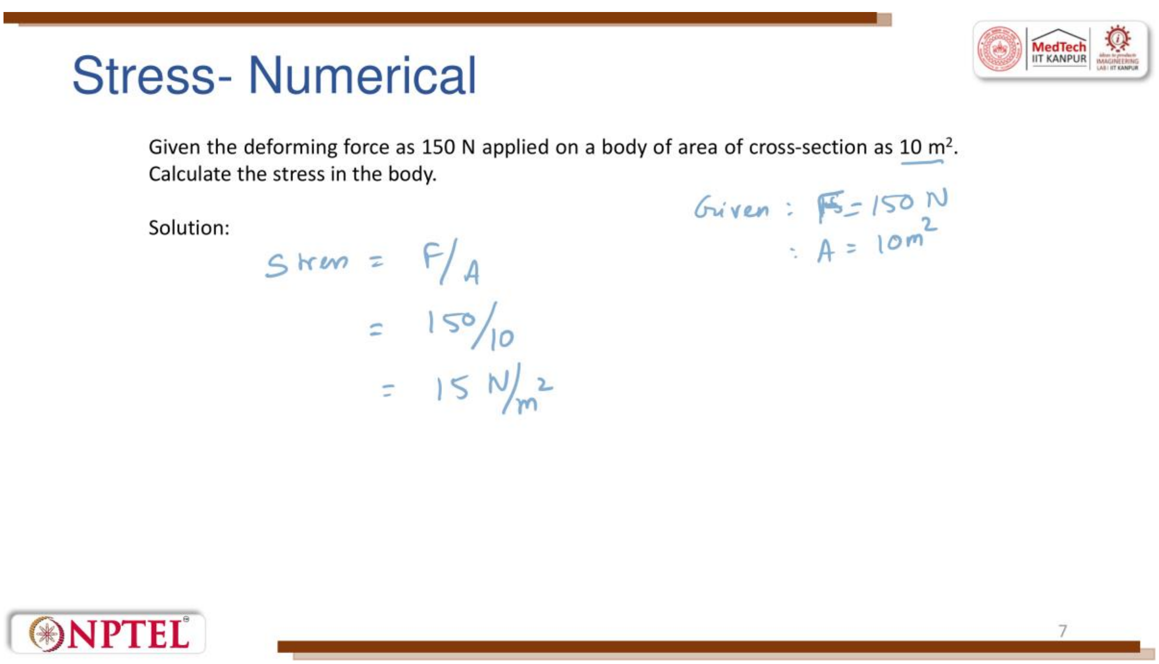
Maybe we can take a jelly candy. You put that candy in between the two fingers. You start pressing it. When you start pressing it, both the sides are equal force. So, it occurs when equal and opposite forces are applied to decrease the length of the rod, which creates a restoring force per unit area, which is perpendicular to the cross section.



You have another force, which is called as Shear stress. Shear stress arises when equal and opposite force act tangentially to the surface of an object causing one face to be displaced relative to the opposite face. One face. So, these are two phases. So, you apply in these two phases. So, it is force acting tangentially to the surface of an object. It is defined as the force tangent to the surface divided by the area of the surface, ok.

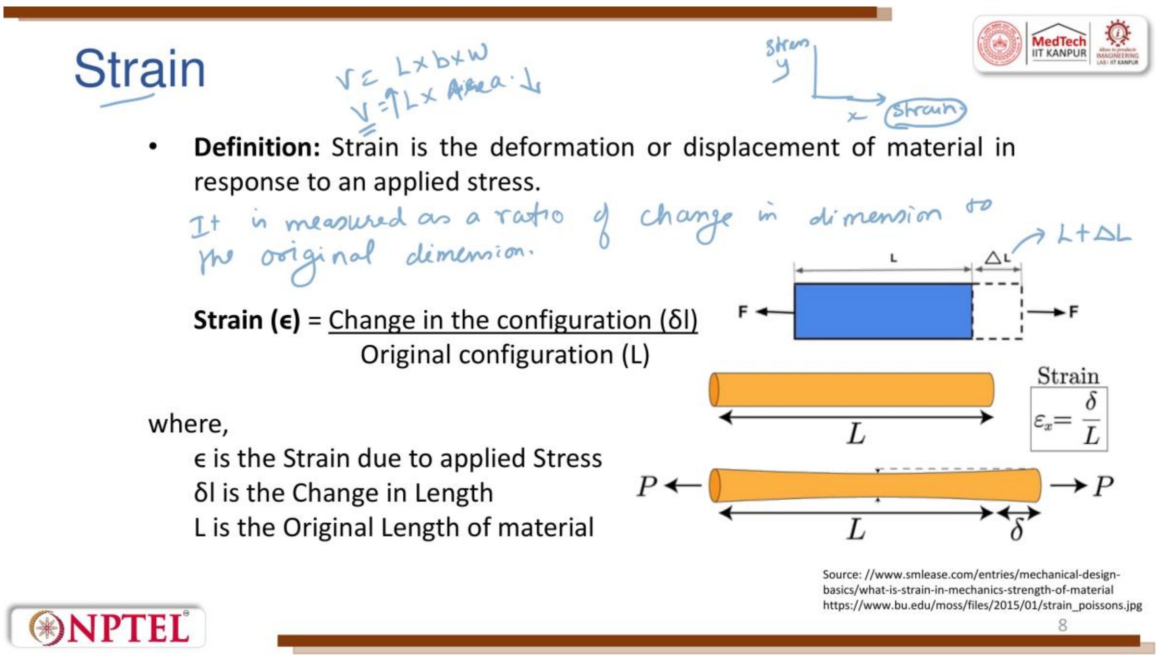
So, area of the surface in metal cutting predominantly, it will be shear force. Metal cutting means when the chip material is removed, it is always shear force bulk stress which is also called as Volumetric stress or Hydraulic stress. When an object is immersed in a fluid, the fluid exerts a force on its surface, decreases its volume, is called as Bulk stress. So, here what do we do is, we try to take the object and apply pressure all around. So, here it was equal and opposite, but it was all around here. For example, you take a tea cup and then you try to keep it at the atmosphere.

Now you go inside the sea, down the sea. When you keep going down and down, the pressure what is exerted on the cup will try to shrink the cup. So that is what we say. When an object is immersed in a fluid, the fluid exerts a force on its surface, decreasing its volume.



So now let us try to make an attempt in solving a numerical problem. Given the deforming force as 150 Newton applied on a body of area which has a cross section of 10 m^2. Calculate the stress of the body.

$$Stress = \frac{F}{A}$$
$$\frac{150}{10} = 15\ N/m^2$$



Now, let us go to the next topic which is Strain. Where does the Strain come? When we try to plot X and Y, along the X axis, you have strain and along the Y axis, you have stress.

So, now we are more focused towards the strain. So, what is Strain? Strain is the deformation or displacement of material in response to an applied stress.

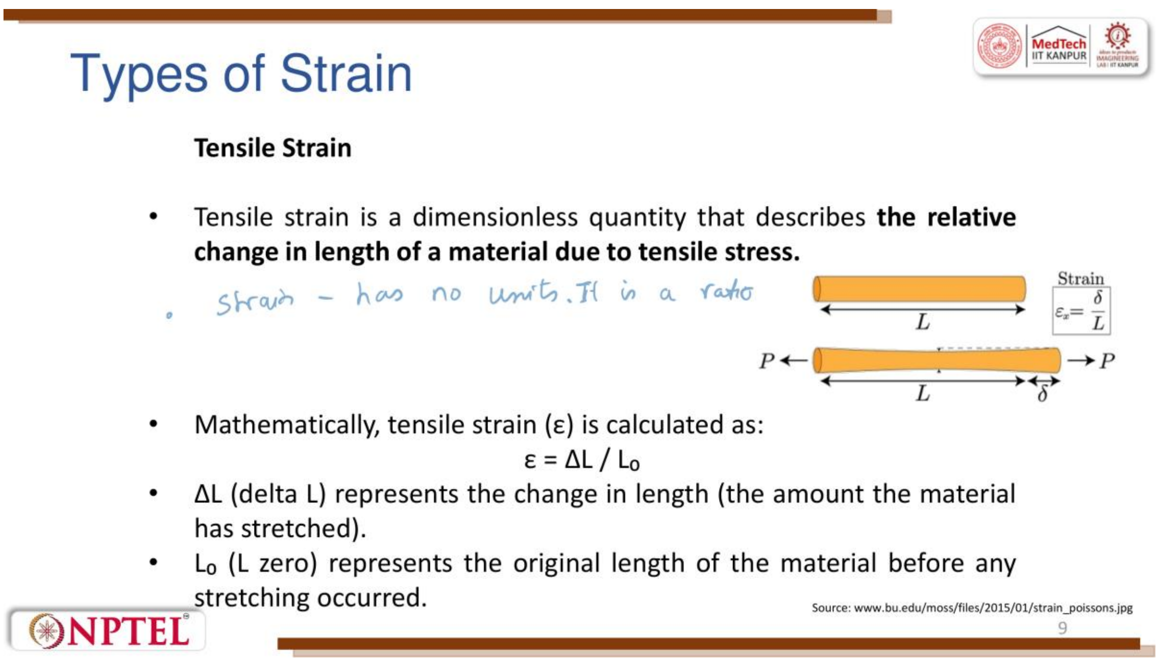
$$Strain\ (\epsilon) = \frac{Change\ in\ the\ Configuration\ (\delta l)}{Original\ Configuration\ (L)}$$

So, it is F, you are trying to pull the object, it is F, initially it was L, L0 has added, so now the length will be $L + L0$.

Initially it was L, now it is increased length is δ L, so it will be L + δL. So, when you write it in the formula, strain is nothing but epsilon, epsilon is nothing but change in the configuration δL by original configuration. So, this is a rod. This is of a length L. So now when you try to pull the rod by a force P, you see there is a constant volume. So constant volume means volume is equal to length into breadth into width. So, in a rod it is going to be volume is going to be length into diameter that is area, right.

Length into area. So, this is constant. Now, when you keep on be increasing, what will happen is the volume constancy is maintained. So, area has to decrease so that the length can increase to maintain the constant volume. So, here what happens? The diameter what was there is now reducing and whatever is getting reduced is extended by del.

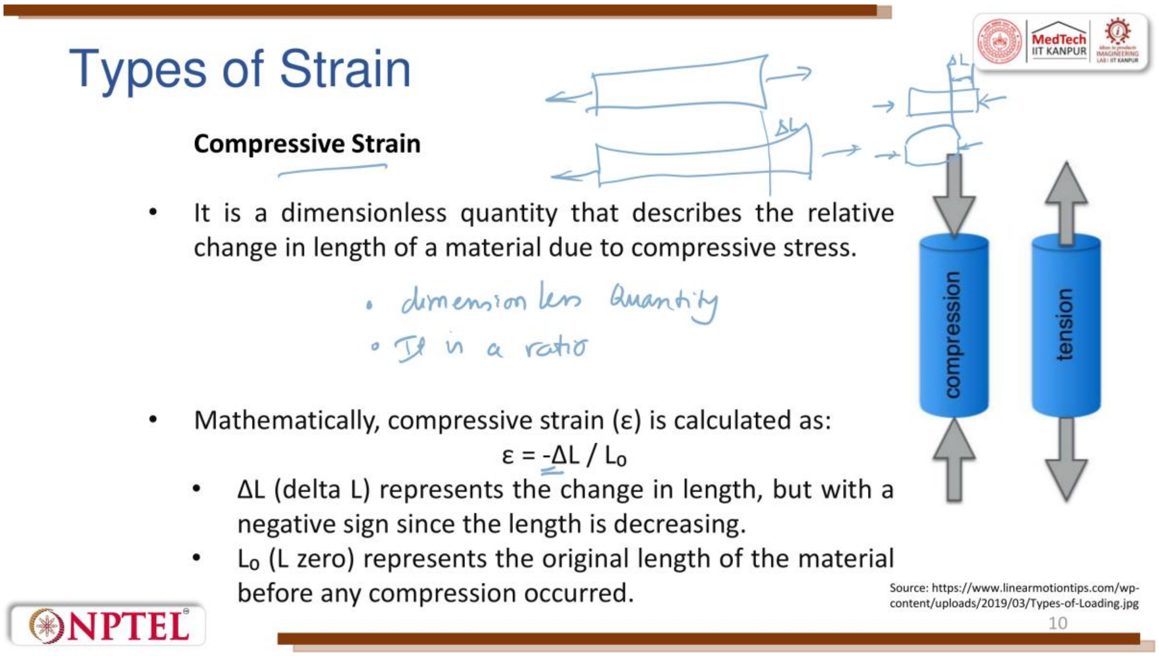
So, strain is nothing but del by L. So, this is change in the configuration to the original configuration. So, strain is due to applied stress. ΔL is the change in length and L is the original length.



So tensile strain means it is a dimensionless quantity that describes the relative change in length to the material due to the tensile stress, right. So, it is you are trying to pull, it is tensile.

So, this is what is the response which happens. So, here the most important thing is the strain has no units. It is ratio. Mathematically, tensile strain is calculated as

$$\epsilon = \Delta L / L_0$$



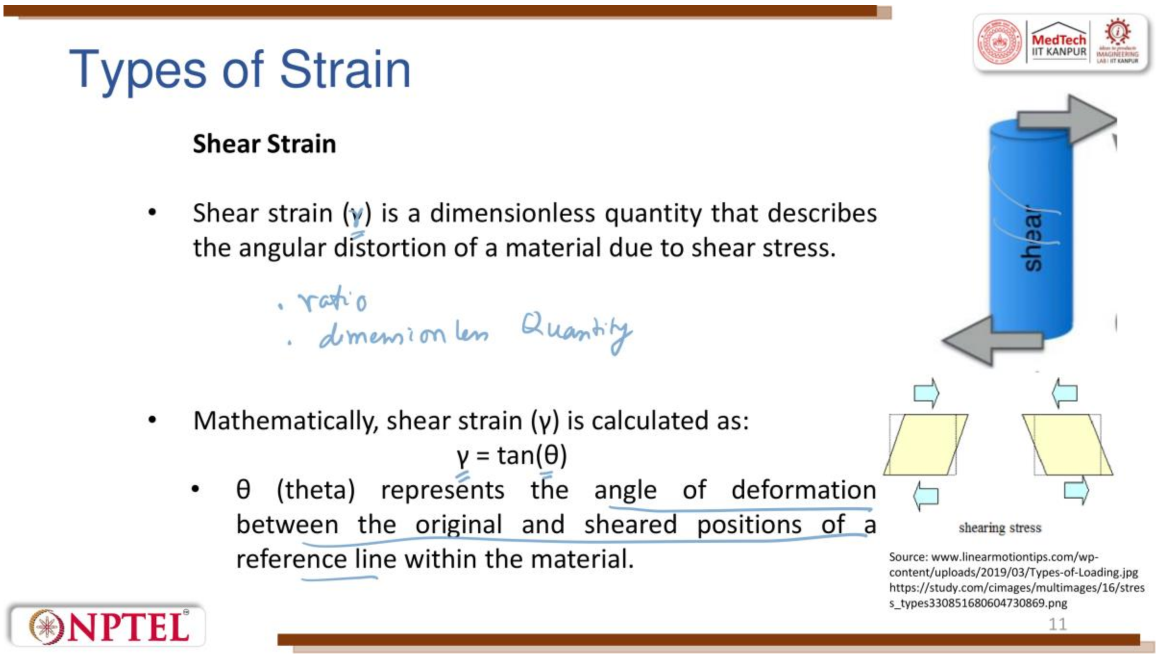
Like tensile, we also have Compressive strain. So tensile and compressive. It is a dimensionless quantity that describes the relative change in the length of a material due to its compressive stress. Again, here it is a dimensionless quantity. It is a ratio. So, it is represented as -δL. So, you are compressing.

There what happened? So, when you apply tensile, so it might go like this little bit, right. Not be so much. It might go like this. So, this is for tensile.

So, because of that, the δL increased, right. But in compression what happens, if you have something like this compression, so here it will become like this. There will be a reduction in δ L. So that is why it is expressed as

$$\epsilon = -\frac{\Delta L}{L_0}$$

ΔL represents the change in the length and L0 represents the original length of the material before any compression could occur. Shear strain, we have tensile stress, compressive stress, shear stress.



In the same way, we have tensile strain, compressive strain and shear strain. Shear strain is represented by γ. It is a dimensionless quantity that describes the angular distortion of a material due to shear stress. So, you are trying to shear. So, what is that?

It is almost like you hold both sides and twist. So, it can happen something like this. So, here again it is a ratio and a dimensionless quantity.

$$\gamma = \tan(\theta)$$

where θ represents the angle of deformation between the original and the sheared position of a reference line with the material. So here they would try to have a θ component which is not there in the previous two.

There the θ will be almost along the straight line. So, you should please make a note of it. The angle of deformation between the original and the shear position of a shear line with the material. So, Stress-Strain relationship.

Stress-Strain Relationship

- **Elastic Region:** The material returns to its original shape after the stress is removed.
  - Hooke's law: $\sigma = E \varepsilon$ $\quad E \Rightarrow$ modulus of elasticity (Young's modulus)
- **Plastic Region:** Permanent deformation occurs after yielding.
  - **Yield Point:** The stress at which a material begins to deform plastically.
- **Ultimate Strength:** The maximum stress a material can withstand.
- **Fracture Point:** The stress at which a material breaks.

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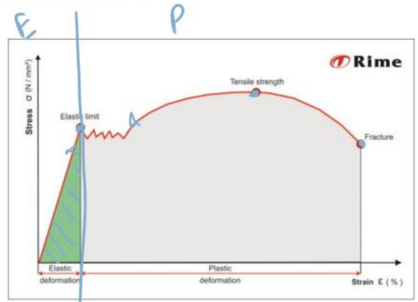
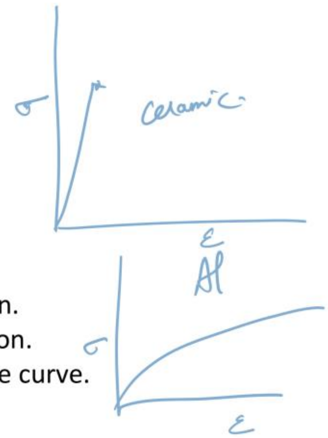
In stress-strain relationship, there are two regions. One is elastic region and the other one is plastic region. In Elastic region, the material retains its original shape after the stress is removed. There is a law which is called as Hooke's law which says stress equal to Young's modulus E into strain, right. So E is modulus of elasticity or it is called as Young's modulus, right. So, Plastic region is permanent deformation occurs after yielding.

So, in this plastic region, we have three more points. One is called as Yield point. The stress at which a material begins to deform plastically. It is non-reversible or irreversible change in the material property. Next, you will have been ultimate deformation which is the maximum stress. A material can withstand and the last one is fracture point, the stress at which a material break.

Stress-Strain Curve





- **Proportional Limit:** The end of the linear elastic region.
- **Elastic Limit (Yield Point):** The start of the plastic region.
- **Ultimate Tensile Strength (UTS):** The peak point of the curve.
- **Fracture Point:** The point where the material breaks.

Source: https://media.tollenaar.io/images/Characteristics.width-2176_IshMk2i.jpg

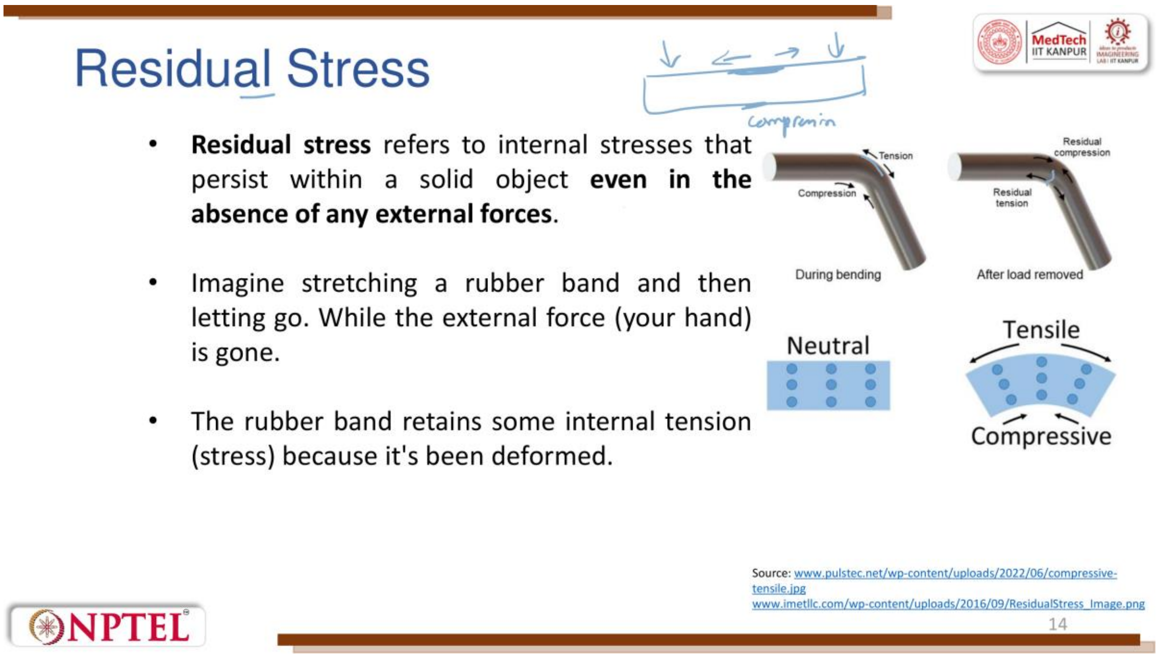
So, when we plot this stress strain curve, we can see here this portion is called as elastic region and this portion is called as plastic region. So, elastic region means when the load is applied and removed, it will regain its shape. So, you remember, we also saw in friction. When an object is there, we try to pull the object. It keeps on resisting.

After a certain point, it starts moving. In the same way here, this is a point till which the material resists to deform. So, this portion is elastic region. This portion, everything is elastic region. And for approximation many a times, what we do is we try to take triangle formula and then we try to use to find the area under the curve.

So, proportionality limit. The end of the linear elastic region is called as Proportionality limit. So, the next one is Elastic limit. It is the yield point, the start of the plastic deformation, a plastic region. It starts from here; it has a crimp coming here and then it starts going high. So, this portion is called as Ultimate Tensile Strength.

So, ultimate is the peak point of the curve. Then at last it is going to be fracture point. The fracture where the material fails. So, this region is called as elastic region. This region is called as plastic region.

Elastic deformation, Plastic deformation. This is called as Elastic limit. By doing or by looking at the stress strain curve, we can try to figure out.



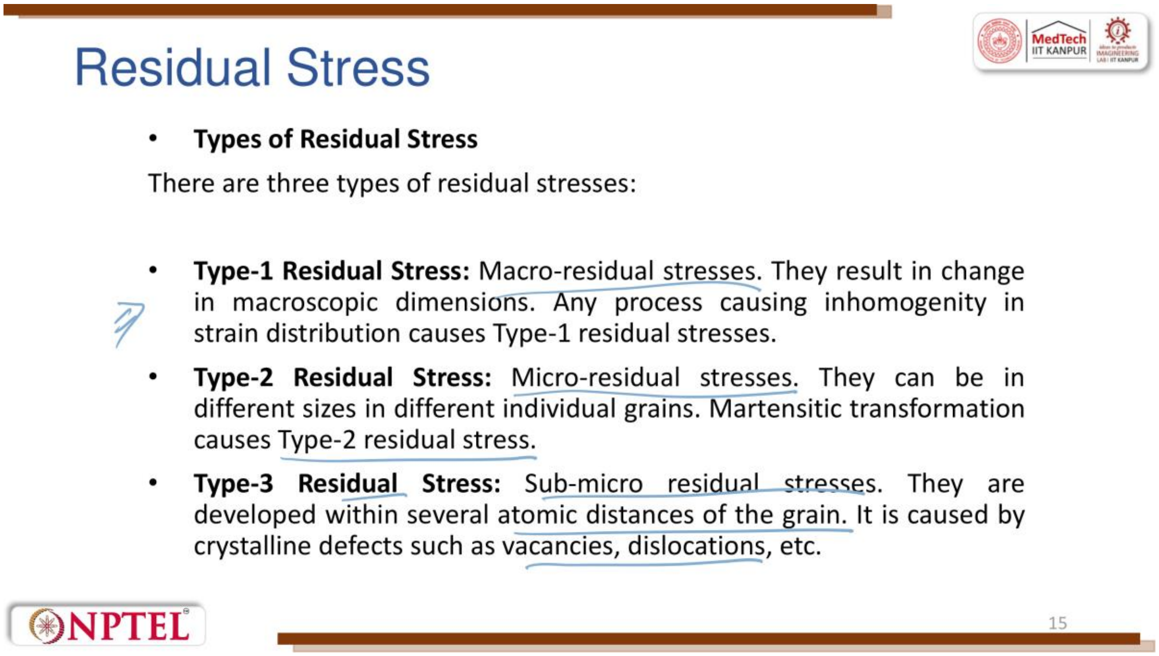
What will be the residual stress which is happening? For example, you go here and you remove it or you go here and remove it.

What happens to the material? So, those things to evaluate, we have to understand a topic called as residual stress. By the way, this graph is a typical graph. In real time, you will get a graph like this for ceramics. This is for ceramics.

You might get a graph like this for aluminium. So here it is stress versus strain. So, the response from material to material, it differs for a stress-strain curve. Residual stress refers to the internal stress that persist within a solid object even in the absence of any external force. So, you bend and keep slowly what will happen it will try to relax.

When you try to bend a pipe, you will see here at the top end skin, there is a tension or a tensile stress coming. In the underside, what you get is a compression. So, if you try to take a rod and if you try to bend it, this portion, the skin will undergo tensile and this portion will undergo compression. So, once it undergoes tensile and compression, there is certain amount of stress which is internally present in the object. So, the Residual stress refers to the internal stress that persist within an object even in the absence of the external force.

Then slowly these forces will, the residual stress only leads to the crack formation and failure. Imagine stretching a rubber band and then letting go. While the external force, your hand is gone, the rubber band retains some internal tension because it has been deformed.

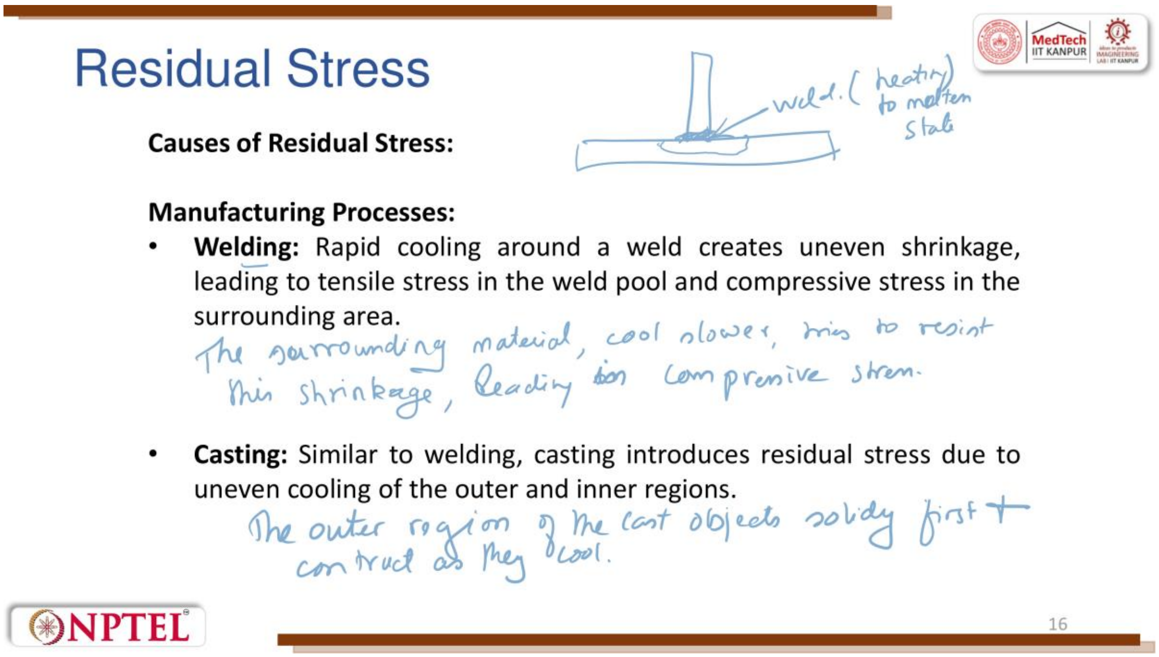


There are three types of residual stress. Type 1, type 2 and type 3. Type 1 residual stress are macro residual stresses. They result in change in macroscopic dimensions. Any process causing inhomogeneity in strain distribution causes type 1 residual stress. In type 2, it is Micro residual stress. This is macro, this is micro residual stress.

They can be in different sizes, in different individual grains. Martensitic transformation causes type 2 residual stress. So, type 1, type 2. What you can see by eyes is macro. So that is type 1. What you can see under a microscope is called as type 2.

So, it is Micro residual stresses. They can be in different size in different individual grains. Martensitic transformation causes the type 2 residual stress. Type 3 residual stress are sub-micro-residual stresses. They are developed within several atomic distance of the grain.

It is caused by crystalline defects such as vacancies and dislocations. There are three types. To a large extent, our course now will be focused only on the macro-residual stress. You have micro, you have Sub-Micro-residual stresses.



What are the Causes of Residual stresses? While doing manufacturing or during manufacturing process like welding, casting, these residual stresses play a very important role. Rapid cooling around a weld surface created uneven shrinkage. For example, you try to melt a material and then you try to pour a material. You will never get a straight line there. The material shrinks, expands, rapid cooling happens.

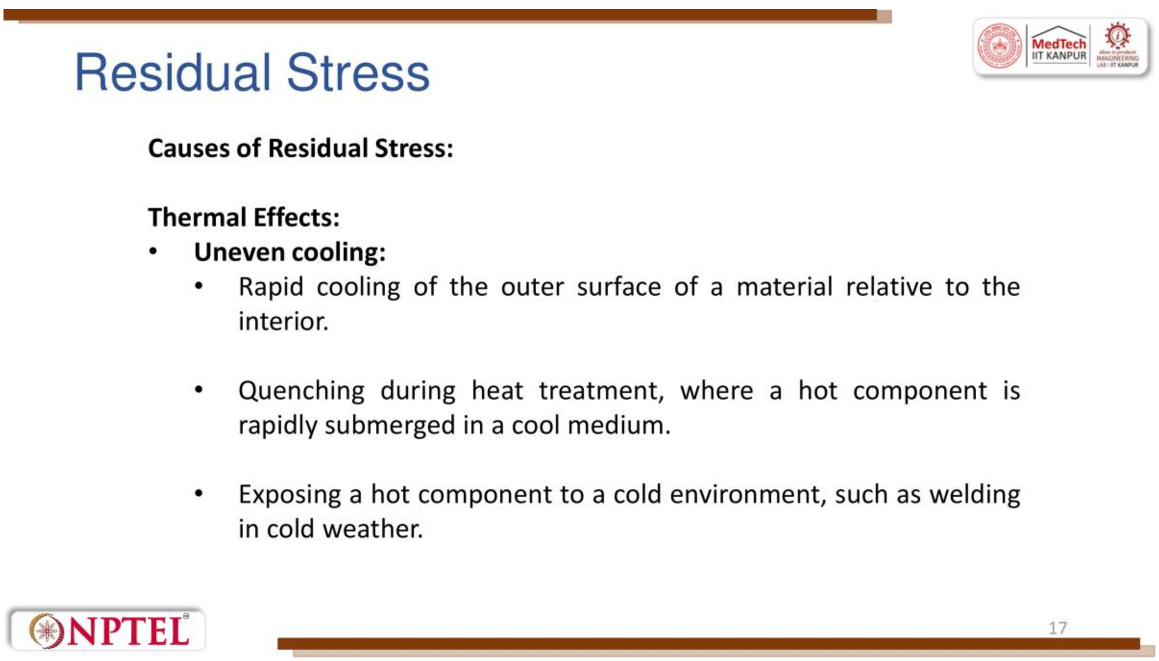
So, this leads to tensile stress in the weld pool and compressive stress in the surrounding area. So, what we are trying to say is suppose you have two metals to be joined. Two metals to be joined, so here let us assume you are welding. This is a weld. So, once you finish your welding, what is welding?

You are heating the material to molten state and then allowing it to cool. So rapid cooling around the weld creates uneven shrinkage leading to tensile stress in the weld pool and compressive stress in the surrounding area. So, this is the surrounding area. So, the surrounding material cools slower, tries to resist, this shrinkage, leading to, leading in, compressive stress, ok. So, when you heat rapid cooling tensile when it cools it tries to pull material, right and when it is trying to pull material, the surrounding surface has a larger surface, the heat flux is low. So, the surrounding material slowly cools, so that tries to resist the shrinkage which leads to compressive strength.

Same way the other manufacturing process is casting. Similar to welding casting introduces residual stress due to uneven cooling at the outer and the inner region. Casting and welding as of now, you should try to understand little bit. In welding what happens, you will have a rod, you try to melt, it is a small melt. A small area of melt happens or it can be a small third party melting which happens because of you apply a very high current.

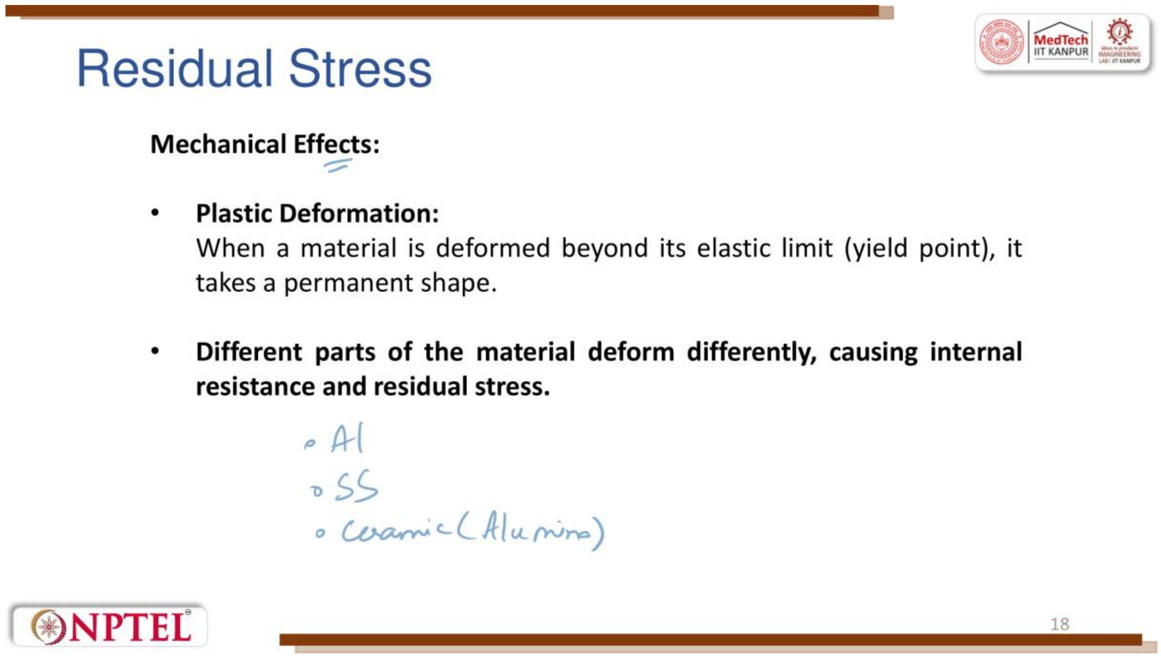
So, and then you drop it in the gap. In casting what happens? You try to melt a large area and then pour. So, it is like a liquid. So, cast is taking a solid, melt it, then it comes to the casting process. So, here similar to welding in casting pulses also you will have multiple residual stresses which are there.

The outer region of the casting, cast objects solidify first and contract as they cool. Because of heat, you have this residual stress which is happening.



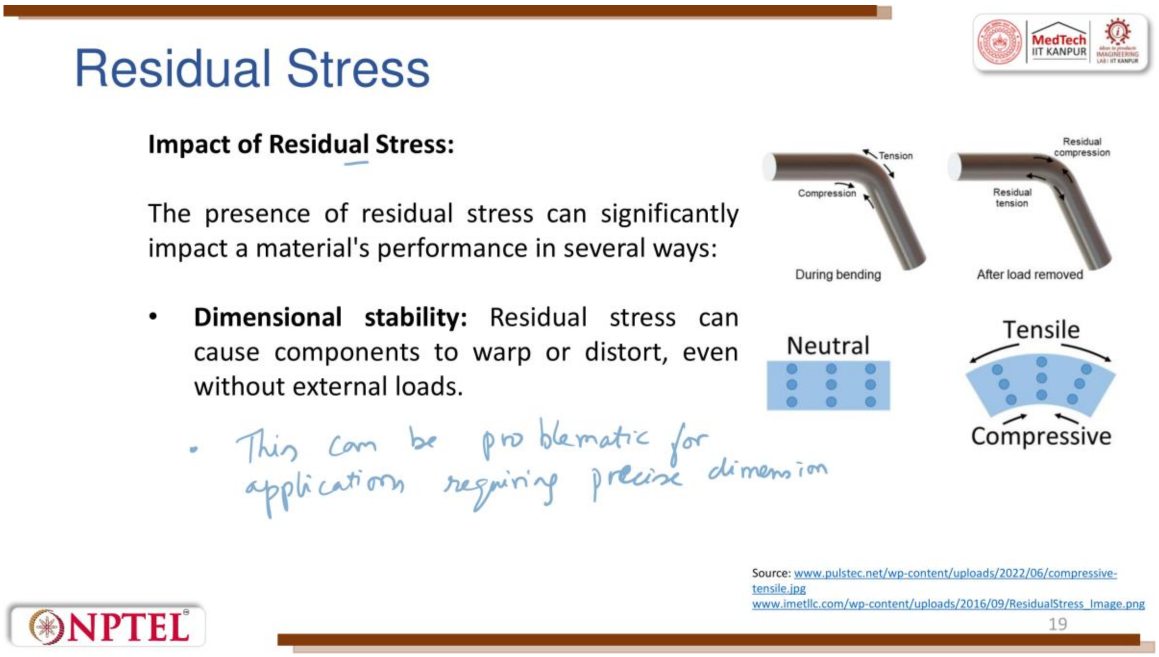
So, thermal effects, uneven cooling, rapid cooling of the outer surface of the material relative to the interior leads to thermal residual stress. Quenching during heat treatment, quenching is you try to heat it and then you try to cool it immediately. You could have seen in the iron smith, when he wants to deform an iron, he keeps on heating it and then what he does is he tries to deform it and then quench it.

So, quenching during heat treatment where a hot component is rapidly submerged in a cool medium. Another thermal effect is exposing a hot component to a cold environment such as welding in cold weathers. All these events which happens during manufacturing process where thermal is dominating leads to residual stress.



You can also have residual stress getting introduced by mechanical effect. So, while plastic deformation, a material is deformed beyond its elastic limits which takes a permanent shape.

So, while doing mechanical effect also the residual stress gets built in. Different types of material deform differently causing internal resistance and residual stress. So, different types of material, you take aluminium, you take stainless steel, you take ceramic, alumina tile, if you take all those three, all of them have a different kind of material response and which causes, it can be heat, it can be mechanical, which causes internal resistance and residual stress.



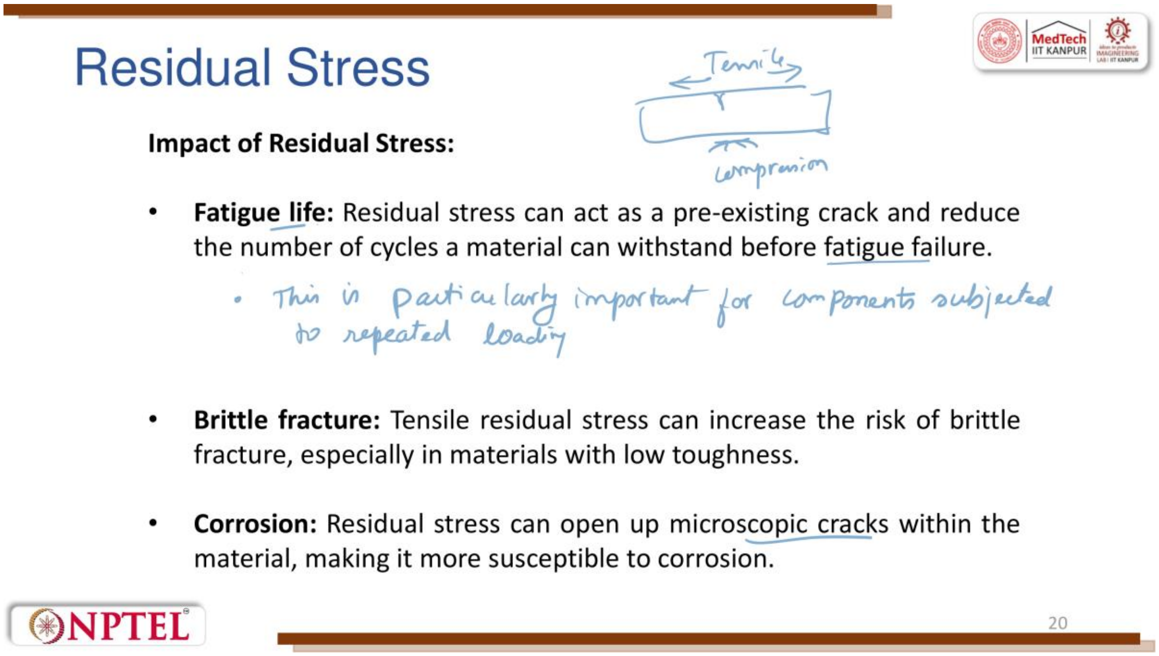
So, what is the impact of residual stress? The impact is the presence of residual stress can significantly impact the material performance in several ways.

Dimensional stability may be lost residual stresses can cause components to warp or distort even without applying external force. Many a times you would have seen, once you heat a material and then you leave it. Let us take a simple example, you take chapati and then put the chapati into your microwave oven, heat it for 2-3 minutes. Once the water goes, you will see there the entire chapati will be warped or deformed. The water left so the dimension stability is lost.

So, this is nothing but thermal residual stress getting introduced in the chapati. So, in the same way, you also will have dimensional stability. So dimensional stability plays a very important role. So, this can be problematic. When you are doing turbine blades, when you are doing boilers, when you are doing windmills, right.

So, all these residual stresses are very important. This can be a problematic for applications requiring precise dimensions, right. Very small hole you have in that hole or you have a thin foil, you are trying to weld which is very common in satellite applications. They have thin foils to be welded. So, then there will be a thermal residual stress, it will try to distort.

So, this dimensional stability, when you go smaller and smaller in your region, it will try to have a huge effect.



The other thing are it will have a direct impact on the fatigue life, brittle fracture and corrosion. So, fatigue life, the residual stress can act as a pre-existing crack and reduce the number of cycles, a material can withstand before fatigue failure. So, this generally happens with gear where there is two gears are mating and then you have where there is a chain and a sprocket. So, where there is maintaining and the bearing.

So, everywhere this fatigue life comes into existence. How many cycles it can withstand? So, here this is particularly important. for components subjected to repeat thread loading. Brittle fracture, here the tensile residual stress can increase the risk of brittle fracture, especially in materials with low toughness. For example, ceramics.

So, heating, cooling, heating, cooling, there will be a brittle fracture. And corrosion, the residual stress can open up microscopic cracks, because if there is, you take a rod, if there is a tensile at the top, stress at the top, and a compression at the bottom, you are bending it or you are heating it. So, this is tensile and this is compression tensile compression, when you do that there are cracks so through these cracks, the corrosion grows, that is why corrosion, the residual stress can open up micro cracks within the material making it more susceptible to corrosion.

Residual Stress

Beneficial Applications of Residual Stress:
While residual stress can be detrimental, it can also be beneficial in certain situations. For example:

- **Shot Peening:** This technique introduces compressive residual stress on the surface of a component improving its fatigue strength and resistance to crack initiation.

- **Surface Hardening processes:** These can introduce compressive residual stress that enhances wear resistance.

- **Tempered Glass:** The rapid cooling process creates compressive residual stress on the surface, making the glass stronger and more resistant to breakage.

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There are some benefits also because of this residual stress. So, they are shot peening, surface hardening process, tempered glass.

So, all these things are some of the benefits which we get because of the residual stress. While residual stress can be detrimental, it can also be used as beneficial in certain situations. For example, Shot Peening. This technique introduces compressive residual stress on the surface of the component. For example, when you are making a component, you know very well this portion is going to have tensile stresses and the bottom or in between you will have compressive stresses.

Now these tensile stresses will lead to failure. I wanted to remove this tensile stress. So, then what do I do? At the top I try to give a compressive stress. I try to give a compressive stress.

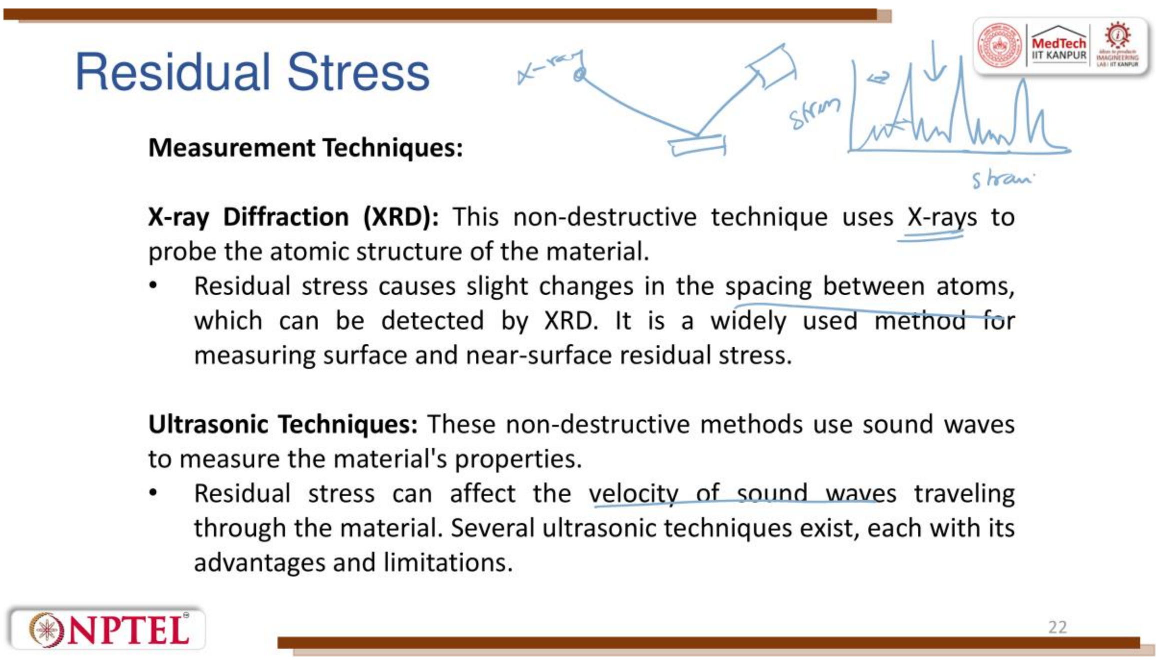
So, when I try to give a compressive, the tensile vanishes away, compression stresses are getting introduced. Once compression stresses are introduced, the life expands. So, when we have to apply a constant load on top of it, that is nothing but shot peening. This technique introduces compressive residual stress on the surface. So, how do you do it? Either you hammer it or you use a ball. You use like a shot.

All these shots hit on the surface. Because of hitting on the surface, there is a compressive stress. This tries to bring in a benefit in the performance. This will try to close the cracks which exist. So, improves the fatigue strength and resistance to crack indentation.

Surface hardening process. This can introduce compressive stress that enhances the wear resistance. For example, you heat it and quench it. When you heat it and quench it, what happens? Hard layer comes on the things.

When the hard layer comes, the wear resistance improves. The tempered glass, a rapid cooling process creates compressive residual stress on the surface, making the glass stronger and more resistance to break. So, the glass is a brittle material. When you throw a stone, it immediately breaks. But when you try to temper it, how do you temper it?

Take it to a slightly higher temperature, quench it. So, it induces compressive residual stress into it. So tempered glass are used in windshields.



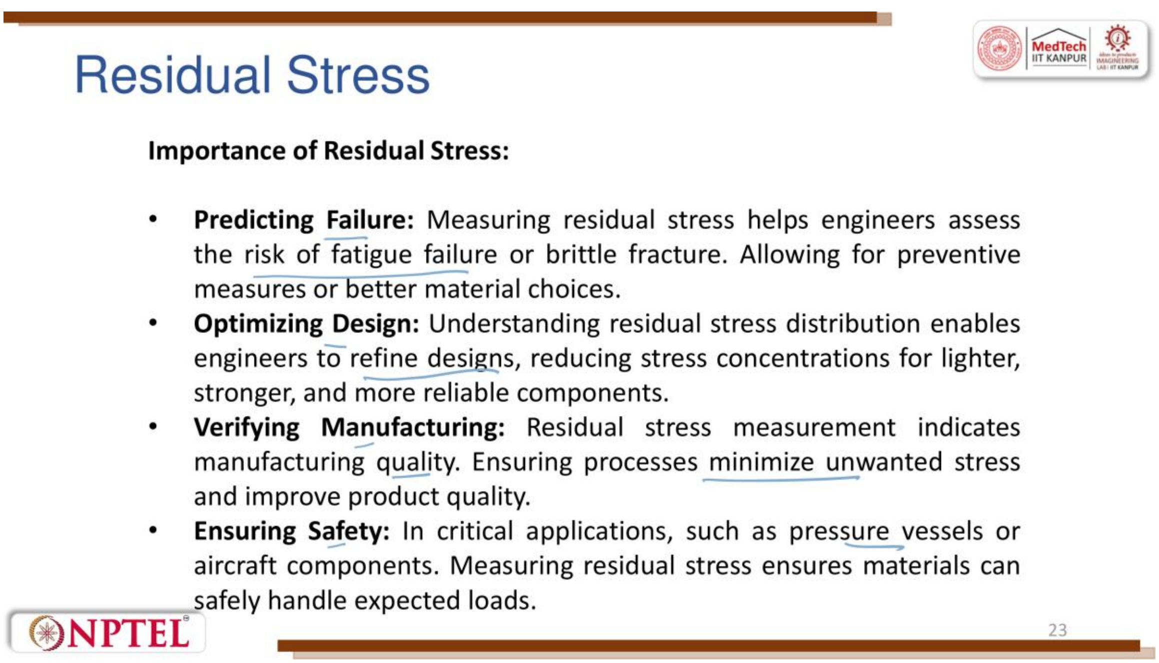
How do you measure this residual stress? Compressive, I said compressive stress can be measured. The Tensile stress can be measured. Shear can be measured. The Residual stress, how do you measure? It is not a straightforward way of measuring the residual stress. There are several non-destructive techniques which are used in measuring. So, again I told you there are type 1 residual stress, type 2 and type 3. So, type 2 and type 3 to a large extent can be measured.

So, the measurement technique we use XRD, ultrasonic testing in XRD. This is a non-destructive technique wherein which we use X-ray. The residual stress causes a slight. So, what happens is you have an X-ray which hits on the sample and then you collect it by a collator or a collector, right. So, when you collect it, what happens?

You will get an output, which is stress, right. Where you get a stress versus strain. You get a response like this. So, here what they say, causes a slight change in the shape, spacing between the atoms, which can be deducted by XRD. This can shift the peak, left or right, or it can widen the peak, or it can reduce the height of the peak. So, how does this happen?

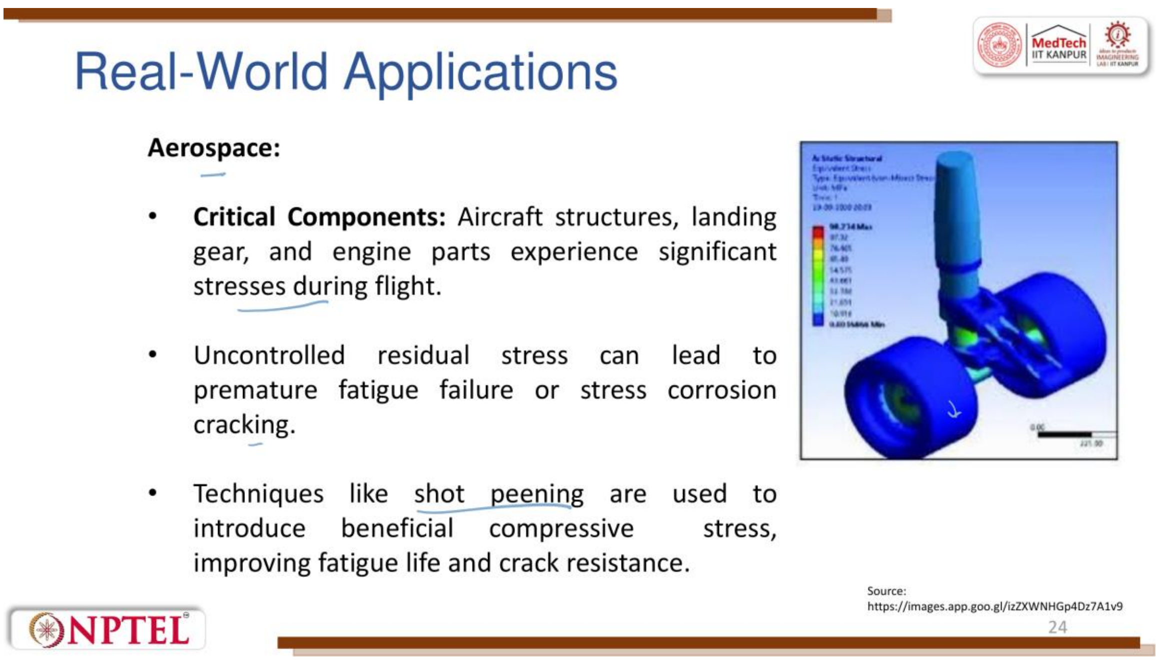
Because there is a change in the spacing. The X-ray comes and hits, it tries to find the change in the spacing. It is widely used method for measuring surface and near surface residual stress. Ultrasonic techniques, these non-destructive methods uses sound wave like X-ray. It uses sound wave to measure the material property.

The residual stresses can affect the velocity of the sound wave traveling through the material. Several ultrasonic techniques exist. Each has its own advantage and limitation.



What are the importance of residual stress measurement? It tries to predict failure. It tries to help us in optimizing design. It tries to help us in verifying manufacturing. It ensures safety predicting failure. Residual stress helps engineers assess the risk of a failing part or a failing system. Optimized design, it understands the residual stress distribution which enables the engineer to redefine the design, verifying manufacturing, it measures, indicates the manufacturing quality, ensures process, minimize unwanted stresses can be done.

Then it also enhances the life of the performance. So, in critical applications like pressure vessels and aircrafts, measuring of residual stress ensures the safety of passenger.



In real life application, in aerospace industry, the critical components like your landing gear, the critical components, aircraft structures, landing gear, engine part experiences significant number of stresses during flight. The uncontrolled residual stress can lead to premature failure or stress corrosion cracks. Many a times, the tires, whatever are used in the landing gear, these tires get worn out very fast.

So, once the tires are getting worn out very fast, the next thing what the engineer does is he goes back and tries to assess what is the deformation which has happened in the shaft. So, moment there is a little variation because of the residual stress, then they try to figure out and correct it. If not, there will be lot of wear and tear on the tyre. So, the uncontrolled residual stress can lead to premature fatigue failure. The techniques like shot peening which we saw or heat treatment can be used to improve the fatigue life and the crack resistance. This happens in aerospace.

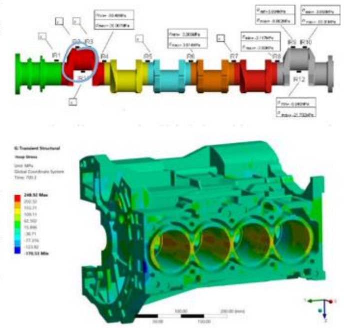
Real-World Applications

Automotive:

- **Engine parts:** Almost engine components like crankshaft, connecting rods, and valve springs etc. are subjected to repeated loads.

Fig. 3. The boundary conditions of the residual stress measurement

- Manufacturing processes like shot peening or forging can be employed to optimize the residual stress profile, enhancing fatigue strength and durability.



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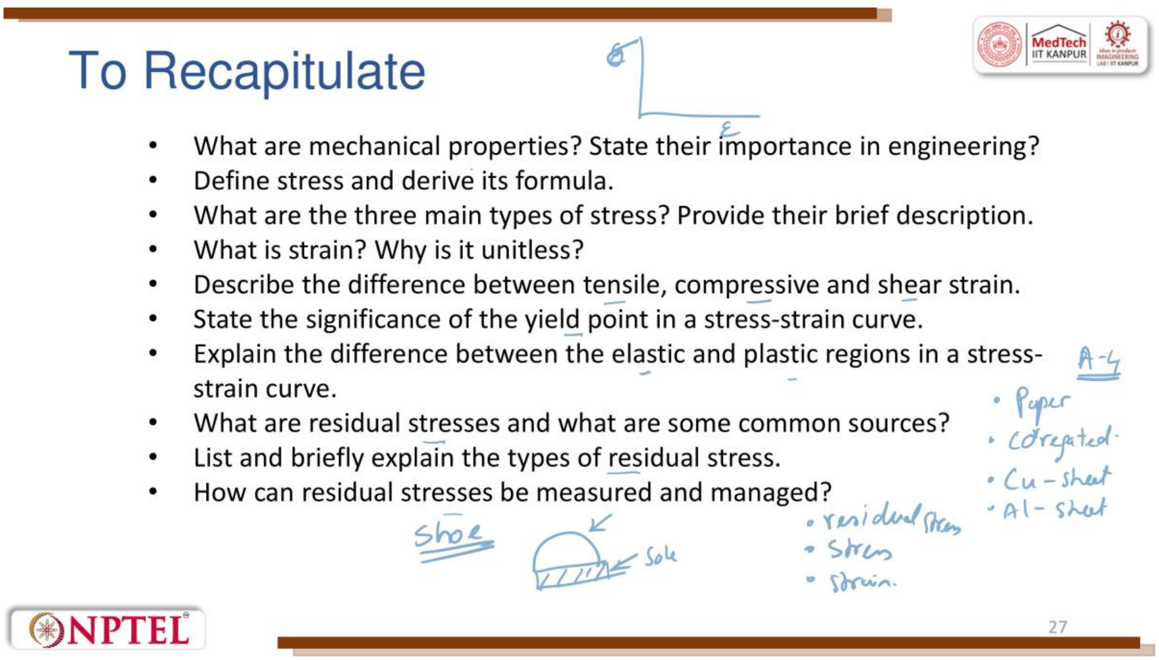
In the same way, it also can happen in automobile. Almost engine components like crankshaft, connecting rod, valve springs, etc. are subjected to repeated loading. The residual stress can significantly impact their fatigue life. So, you see here, here are some of the major points where there is lot of stresses which are there, which will try to have an influence. So, what they do is at these regions, they try to introduce short peening or they try to do a special forging process to improve the residual stress.

Real-World Applications

Civil Engineering:

- **Structural stability:** Bridges, buildings, and other structures experience complex loads due to wind, weight, and seismic activity.
- Residual stress can affect their stability and performance.
- Techniques like stress relief annealing can be used to minimize residual stress and improve overall structural integrity.

In civil engineering also, the residual stress play an important role, structural stability, bridge, building and other structures experience complex loads like wind, weight and seismic activities. So, this also introduces a residual stress and which affects the stability and the performance. So, techniques like stress relieving, annealing can be used. So, all the heat treatment of the rods will be done annealing can be used to minimize the residual stress and improve the overall structural integrity.



A recap of this lecture, we saw what are mechanical properties, state their importance in engineering we saw. Then we saw the definition for stress, derived its formula. Then what are the three main types of stress, tensile, compress and shear? Then what is strain, why is it unitless, what is the difference between tension, compression and shear? What is the significance of yield point in a stress-strain curve? What is the difference between elastic and plastic region in a stress-strain curve?

What are residual stresses? What are the different types of residual stresses? How residual stresses are measured and its influence? Before we close this lecture, some problems for you to understand. First thing is you try to take a sheet of paper.

Try to bend the sheet of paper 10 times of a dimension maybe of A4 sheet, right. Cut a same A4 sheet dimension on a corrugated box. Corrugated box, that means to say corrugated sheet of the same dimension, right. Try to take a thin copper sheet, right. Or take an aluminium foil which you wrap around food. Take that.

They are three different materials all of the same dimensions. Now you try to bend it and relax it for 10 times, 20 times and 30 times. Try to see what is your inference in terms of one, residual stress, stress and strain. So, you just draw a plot, try to say stress versus strain, and then you say number of cycles, maybe did it break or not, what happened, you can try to say. So residual stress, then you will try to say stress and then strain.

So, try to do this exercise. This will give you a feel what is it. And next thing is you try to take your shoe. In shoe, you will have two parts, basically the cover part and then you will have a sole. So now you try to analyze the mechanical property of the cover which wraps on top of your foot and then try to see the sole.

See what are their mechanical properties and see what is their response. These two will try to give you a feel for this chapter whatever we have studied.

References

- D Halliday & R Resnick, Physics Vol-II, Wiley Eastern, 1993
- Hibbeler, R.C., Engineering Mechanics: Statics, Pearson, 2016.
- Khurmi, R.S., & Gupta, J.K. (2005). A Textbook of Machine Design. EURASIA PUBLISHING HOUSE (PVT.) LTD.
- H.K. Malik & A.K.Singh, Engineering Physics, Tata McGraw Hill, 2011

Here are some of the references which we have used for this lecture.

Thank you very much.