Basics of Mechanical Engineering-1

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Week 08

Lecture 34

Britleness and Ductility

Brittleness and Ductility, both properties are very important. You have to choose Brittleness for some application, Ductility for other set of application. During the time of emergency, when you are travelling by train or by bus or if you are in a building where there is a fire situation, when the emergency happens, we are always guided to go to a box which is transparent and has a glass covering. Why is that so? We are trying to use design for failure.

By one small impact, you should be able to access to the button or the hammer or whatever, hose pipe to get to attend to the situation. So, where brittleness is important. Here, it is planned for design for failure. Ductility. Ductility is very important.

When I take a sheet and I start bending the sheet, to what extent I can bend or what extent I can draw a cup, there ductility comes into existence. And when we talk about ductility, we also try to have toughness property integrated into it. Both of these things can be easily found out by doing a stress-strain relationship graph.

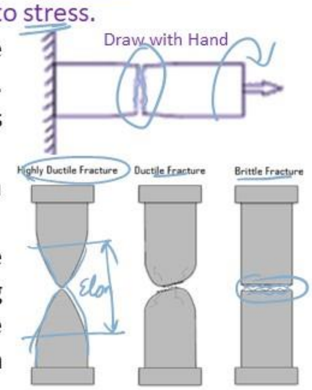
Contents

The content of today's lecture is going to be Brittleness, Factors Influencing Brittleness, Testing for Brittleness, Ductility, Factors Influencing Ductility, Testing for Ductility, case study wherein which brutal failure in Liberty Ship, then case study ductile failure of De-Havilland comet. And finally, we will have a recap of this lecture.

Brittleness

Brittleness is the tendency of a material to break or undergo a fracture showing little to no plastic deformation when subjected to stress.

- Such materials absorb very little energy before failing, leading to a sudden, often catastrophic break.
- It is characterized by lack of ductility. Such materials do not significantly deform before breaking.
- Brittleness is typically associated with materials such as glass, ceramics, and some high-strength metals.
- Such materials tend to have crystalline structure with strong but inflexible atomic bonds contributing to inability to deform plastically. Understanding the brittleness is crucial for applications where sudden failure can have serious consequences.



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Brittleness is the tendency of a material to break Or undergo a fracture showing little to no plastic deformation when subjected to stress. You take a stress-strain graph. You have a material which fails.

So let us take it for glass or any ceramic material. The Young's modulus will be very high. E is very high for brittle materials as compared to that of ductile materials. So, brittleness is a tendency to break or undergo a fracture, showing no plastic deformation when subjected to stress or subjected to load. The same example I will give you for brittleness, again designed for failure.

Many a times you would have seen in taekwondo or martial arts. In martial arts classes, they always used to demonstrate breaking of a tile. They never will show you breaking of an aluminium bar or a stainless steel bar or a mild steel bar. Another example, if you watch Hollywood or Bollywood or Tollywood or Coleywood movies, you will always see that the hero or the villain will be breaking through a glass and then coming to the spot. Again, this is planned for design for failure.

So, all those things they always consider brittleness. In brittleness, all you have to do is initiate a crack or apply a small impact load. When we apply a small impact load, the load leads to crack formation and then happens a coagulation of cracks that lead to a sudden failure of material. If we move towards ampoule which is used for injection, there also it is designed for failure. You would have seen doctor or the paramedic breaking the ampoule, then they use an injection to take the medicine out for a small dosage for you.

So there also it is designed for failure and it is using the concept of brittleness. Such materials absorb very little energy before leading to failure. It is characteristic by lack of ductility. Such materials do not significantly deform before fracture. Brittleness is typically associated with a material such as glass, ceramic and some high strength metals.

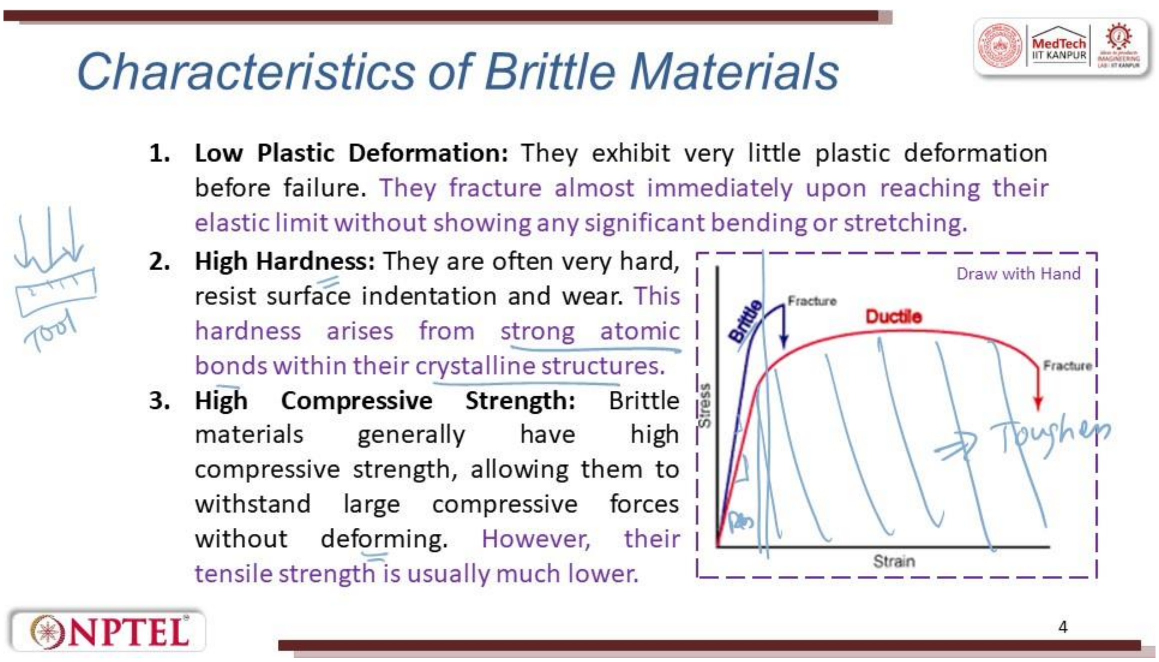
This is a typical response of a brittle material. You will see when you try to do a tensile or when you try to do a shear, it will immediately start fracturing at a place. There will be a complete fracture. There is no plastic deformation. Whereas, when we try to look at a ductile fracture, you will always see they will try to form a cone neck structure.

So this is a neck and cone shape. So it will start elongating. So you can see here there is an elongation. So you can see ductile fracture. This is for a very high ductile material.

This is for a normal ductile material. But for a metal material, you see there is no cup and cone structure form. It shears with a very small instant of plastic deformation. Such materials tend to have a crystalline structure with strong but inflexible atomic bond contribution to the inability of plastic deformation. When we look into microscopical mechanism, here what it clearly says is majority of the brittle materials will have ionic bond.

Ionic bond is perfect bond, so where in which it is locked and any small heating or any small load applying, it will lead to breakage of this bond. So this breakage of this bond directly leads to failure. Understanding the brittleness is crucial for applications when sudden failures can have serious consequences. So a stress-strain graph. So this is what area under the curve where in which we talk about toughness property.

And if it is within the elastic, we talk about resilience property. For resilience for rubber, it is very high. And this is where we try to take the Young's modulus. Within the elastic limit, we try to do the Young's modulus. When we try to do the Young's modulus for brittle materials, you see it will be extremely high. But the plastic deformation is next to negligible.



Low Plastic Deformation, they exhibit very little plastic deformation before failure. They fracture almost immediately upon reaching the elastic limits without showing any significant bending or stretching. It has very high hardness. They are often very hard, resistant surface indentation and wear.

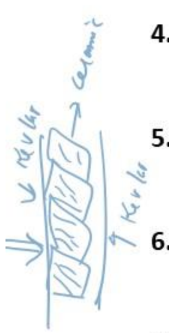
They have very high hardness there. Because of that, that leads to resistance to surface indentation and wear. Because when two surfaces are in contact, when we start trying to have a friction, when we try to move relative motion, there will be always a friction. This friction will lead to wear. In metals, what happens?

The localized temperature goes high. That will try to either soften the material or strain harden the material. If you have declarative property, you will go towards strain hardening. When you have a brittle material, both these properties are not possible. So, softening is not possible, strain hardening is not possible.

So, here what happens, it tries to resist to a large extent where after a certain time, it leads to failure. The hardness arises from the strong atomic bond within their crystalline structure. High compressive strength, brittle materials generally have a very high compressive strength, allowing them to withstand large compressive forces without deforming. When you look at cutting tools, there will be lot of load which is given on top of a tool. So there will be compressive load.

When the chip moves, it will try to give lot of compressive load. Then the compressive load, what happens is the cracks cannot grow. So, the ceramic material or the glass material can withstand very high compressive load. So, brittle materials generally have high compressive strength, allowing them to withstand large compressive forces without deformation. However, with a very little tensile, it just shatters.

Characteristics of Brittle Materials



4. **Sudden Failure:** When subjected to stress, brittle materials fail suddenly and catastrophically, characterized by a sharp, clean break, with little to no warning or plastic deformation.
5. **Fracture Behavior:** They tend to fracture in a characteristic manner, often producing smooth, flat fracture surfaces, which may exhibit patterns such as conchoidal (shell-like) fractures in materials like glass.
6. **Low Impact Resistance:** These materials have low impact resistance and are prone to shattering when struck. They cannot absorb significant amounts of energy before fracturing.
7. **Temperature Sensitivity:** Brittle materials can become more prone to fracture at lower temperatures, as their ability to deform plastically decreases further. This phenomenon is known as the ductile-to-brittle transition.

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Sudden failure is another characteristic of brittle material, which is to be handled with care. Sudden failure. When subjected to stress, brittle materials fail suddenly and catastrophically, characterized by sharp clean break with little to no warning or plastic deformation. The glass bottle, when it is dropped, it shatters. It shatters instantly.

That is a big problem. Nowadays, to come out with this problem, what they are doing is they are trying to have toughened glass. So even when it is dropped down, it does not break so easily. Fractured behavior. They tend to fracture in a characteristic manner, often producing smooth, flat fractured surface, which may exhibit patterns such as conchodial (shell-like) fracture in materials like glass.

Low Impact Resistance. These materials have low impact resistance and are prone to shatter when struck. So use this as an advantage. When you try to hit or do an impact load on a brittle material, it is expected that the brittle material will fracture. But if you can use it for absorbing some amount of shock, so that means to say some amount of redistribution of energy, that is also good.

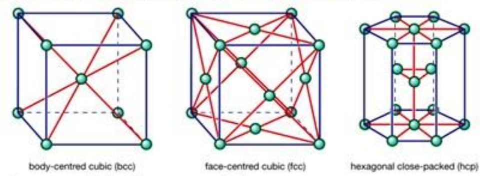
So in a bulletproof jacket if you see, there will be Kevlar which is kept in the front end. There will be again Kevlar which will be kept at the back end. In between they keep tiles, ceramic tiles. When the bullet hits, these ceramic tiles try to absorb energy and shatter. Once they shatter, these are ceramic materials.

Once they shatter, the energy is absorbed. So, so much of energy is absorbed here and only a small amount of energy is further allowed to penetrate and then comes to the human body. So, here nowadays people are working a lot to make sure that low impact resistance that leads to prone to shatter. While it shatters, it absorbs. Temperature sensitivity, brittle materials can become more prone to fracture at lower temperatures as their ability to deform plastically decreases drastically.

This phenomena is called as Ductile to Brittle Transition. This is a very important phenomena which is used.

Characteristics of Brittle Materials

8. **Crystalline Structure:** The atomic structure of brittle materials is usually crystalline, with atoms arranged in a highly ordered, rigid lattice. This structure contributes to their strength but also limits their ability to deform plastically.



9. **Stress Concentrations:** Brittle materials are highly sensitive to stress concentrations such as cracks, notches, or other flaws. These imperfections can significantly reduce the material's strength and lead to premature failure.

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Crystalline Structure. The atomic structure of brittle materials is usually crystalline with atoms arranged in a highly ordered and rigid lattice. So you can see here BCC, FCC or HCP.

Here you see the atoms are tightly held and they are bonded nicely. So crystal structure plays a very important role for brittleness. In a ductile material, we will try to have metallic bond. So there will be transfer of electrons and there will be conductivity. All these things will come into existence.

Stress concentration, brittle materials are highly sensitive to stress concentration such as cracks or knots and other flaws. This imperfection can significantly reduce the material strength leading to premature failure.

The examples of brittle material, Glass used in windows, glasses, drinking glasses, bottles etc. They have very high strength but fracture suddenly. Ceramics including porcelain and aluminium.

Porcelain if you see our tiles whatever is given to our floor. If you drop a heavy load, it tries to shatter. You keep walking on it, it takes a compressive load. But if you keep jumping with a shoe with a sharp edge, then you see the tile will crack. So includes porcelain and alumina is used in ceramic.

High hardness, excellent compressive strength. Excellent compressive strength is there for ceramic. Cast iron used in pipes and machine parts. Pipes also you will see majority of the time they will be taking lot of compressive load. And when you talk about machine parts, cast iron, it will be always used for bed.

So bed is the base of a machine. That will be always made out of cast iron. Cast iron has a property of taking shock but there is no ductility in it. So it will not deflect. It takes shock and it absorbs shock.

It does not fracture so easily. So pipes which are used for sewage pipes, they are all made out of cast iron. Then concrete, common in construction and high compression strength, brittle under tensile strength. So this is also the concrete pipes which are used for construction. They are also part of construction.

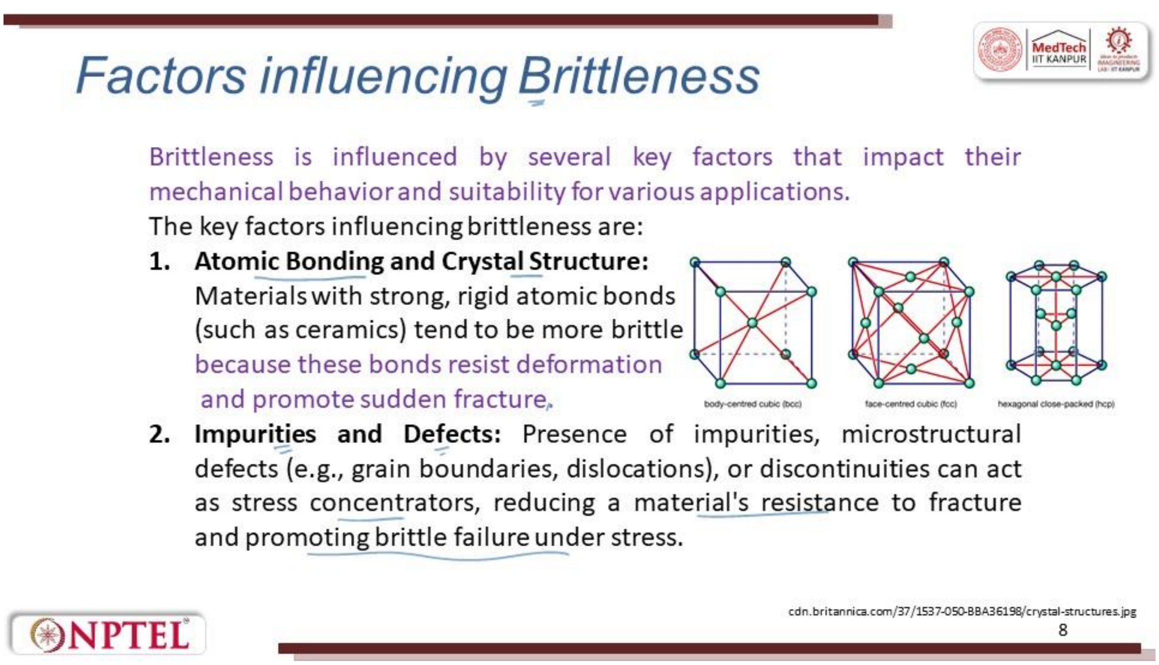
Brittle Material. You can see porcelain material breaking. Once I was visiting South Africa. So it was a very interesting scene. There was a huge market area.

So there was an old man who was sitting in front of a food restaurant. And what he was trying to do is every 15 minutes once he was throwing down a porcelain plate. The porcelain plate shattered. So it shattered and created a huge shrieking noise. So that made every people attention towards that shop.

So by doing so, he was able to attract The customers. So once he broke the porcelain plate, it produced sound. So from that sound, when you turn around, he kept a notice there saying that what is today's menu or what is discount. So you see how beautifully people use porcelain plates for advertisement.

Concrete is also there. Concrete can take extremely good compressive load. Your buildings are all made out of concrete. But very poor plasticity will be there. In order to get out of that, what people do is they try to attach rods or they say tie rods.

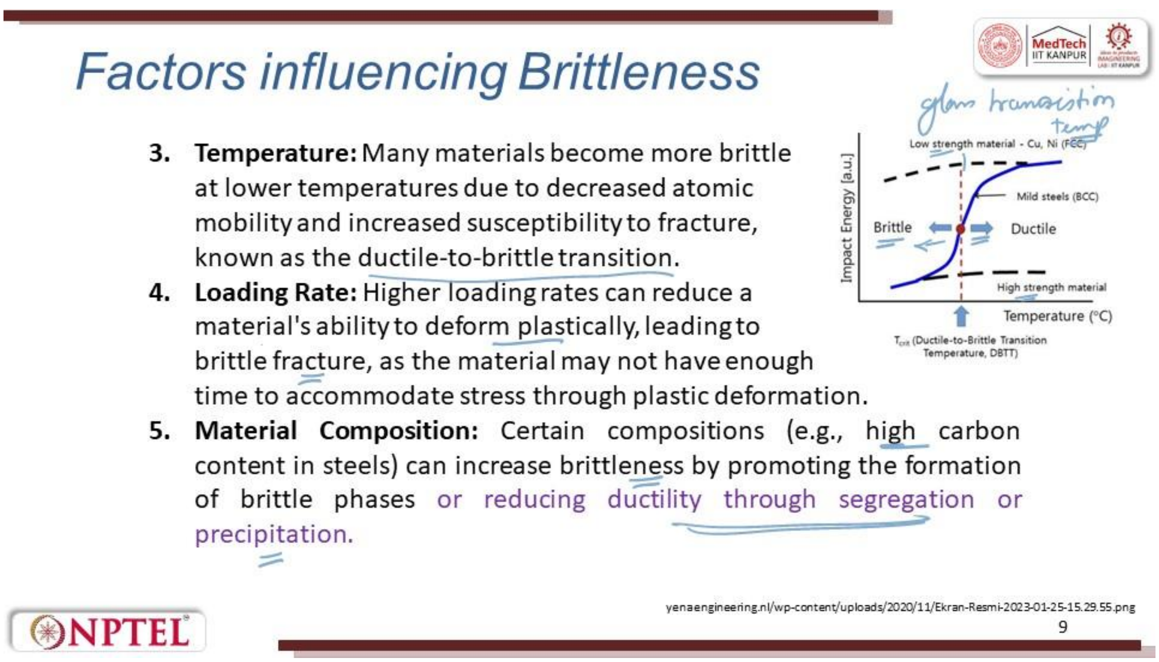
These tie rods will take some amount of plasticity and it will try to take so the concrete will not break. And this is a concept used in all metro rails if you see. They build concrete beams and then they put a tie rod to do it.



The Factors Affecting Brittleness, the brittleness is influenced by several factors that impact their mechanical property. A few factors influencing brittleness are Atomic Bond and Crystal Structure.

Materials with strong rigid atomic bond tend to be more brittle because these bonds resist deformation and promotes sudden fracture. Impurities and defects also influences brittleness. Many a times you see a colored glass. These colored glass are impurities which are added or sometimes it can be defects. When the light passes, it tries to do diffraction and other light phenomena are there.

These defects are used for advantage and sometimes these defects are also used to introduce transparency. Presence of impurities, microstructural defects like grain boundary dislocation or discontinuities can act as stress concentrators, reduce the material resistance to fracture and promoting brittle fracture under stress.

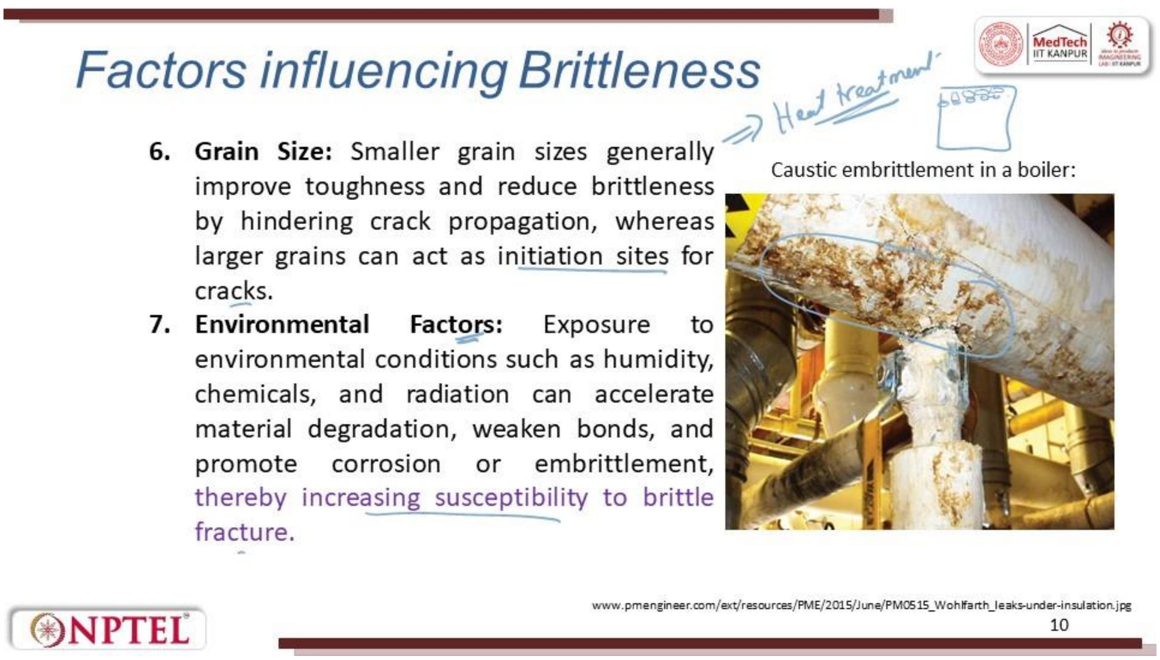


Temperature is also a major influencing factor. So like in metals, in ceramics also you will try to have something like equal to metric point. But in ceramics what we always do is they will call it, ceramics or polymers, they call it as a glass transition temperature.

So there will not be a perfect sharp change, you will have a small change which goes like a slope. So if you see impact energy with respect to temperature, you can draw a midline; below this midline you will have brittleness and above it you will have ductility. so if you see here there is a slope so here you see high strength materials and the top you see low strength materials. So this transition is very important in ceramic materials. Temperature. Many materials become more brittle at lower temperatures due to the decreased atomic mobility and increased susceptibility to fracture.

Known as Ductile to Brittle Transition at low temperatures. Loading rate. Higher loading rate. Impact load is a higher loading rate. Higher loading rate can reduce the material's ability to deform plastically leading to a brittle fracture.

Material composition. Certain composition can increase brittleness by promoting the formation of brittle phase or reduce ductile through segregation or precipitation. So, certain composition such as high carbon steel can increase the brittleness by promoting formation of brittle faces.



Grain size plays another important role. Smaller grain size generally improves toughness and reduces brittleness by hindering crack propagation.

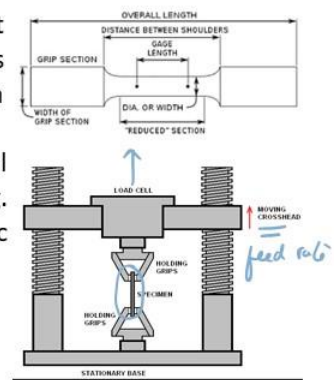
Whereas, vice versa, large grains can act as initiation sites for cracks. So, how do you generate these small grains? What we do is we try to do heat treatment. I am talking about glass or even metals. We try to do heat treatment.

We try to take it to a high temperature, quench it. When we try to quench it, the grains will be formed and all these grains will lead to small grain formation. Environmental factors, exposure to environmental conditions like humidity, chemical, radiation can accelerate material degradation, weaken bonds and promote corrosion or embrittlement, thereby increasing susceptibility to fracture. Environmental factors like Hydrogen Embrittlement can happen. So, you see here concrete which is there which is undergoing damage because of the environmental condition. It can be humidity, chemical or radiation which can accelerate.

Testing for Brittleness

Brittleness is determined by completing a tensile test and calculating the ductility of a material. A material is considered to be brittle if it exhibits low ductility during a tensile test.

- **Tensile Test**: It measures the stress a material withstands while being stretched before breaking. Brittleness is indicated by a lack of plastic deformation before fracture.



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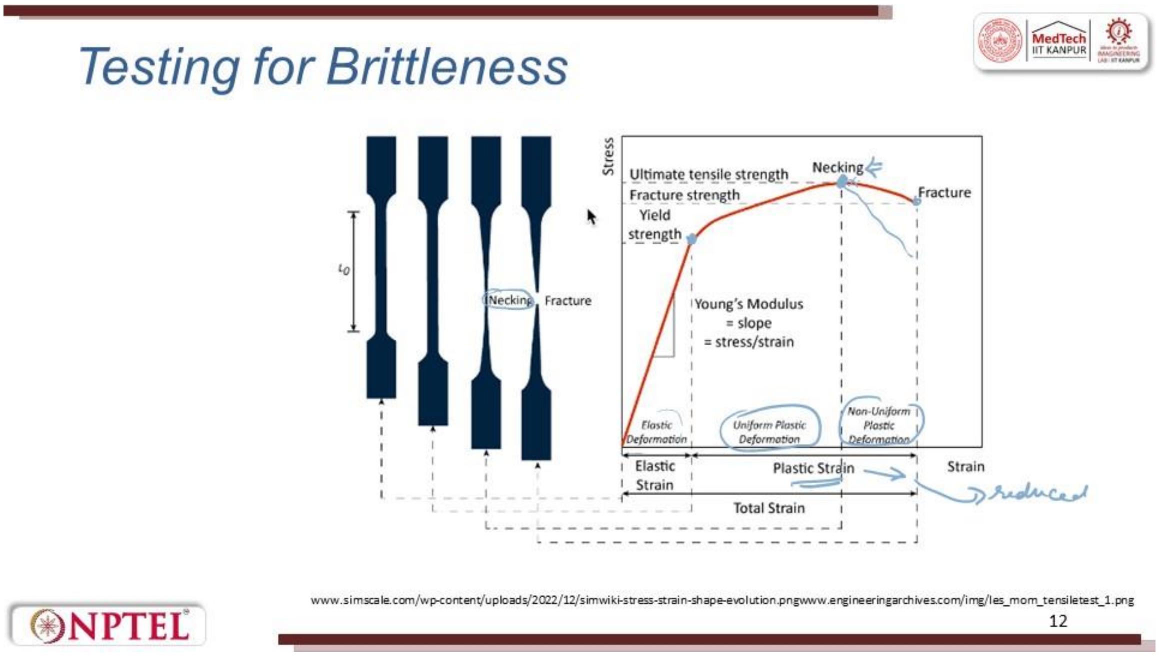
So, for identifying the brittleness, we always try to do a tensile test. Brittleness is determined by completing a Tensile Test and calculating the ductility of the material. A material considered to be brittle if it exhibits low ductility during the tensile test. So, as I discussed in the previous lectures, tensile test you will have a upper jaw, lower jaw.

These upper jaw and lower jaw are used to hold the specimen. The lower jaw is fixed to the frame. The upper jaw is given a strain rate or it is given a feed rate through which it holds the sample and pulls in the top direction. So, this is how the movement of the cross section. So, here what there is a feed rate or a moving rate, right.

So, if you can change this, you can try to create sudden impact or slow feed rates and see what is the material response. It measures the stress, stress a material withstands while stretching before breaking.

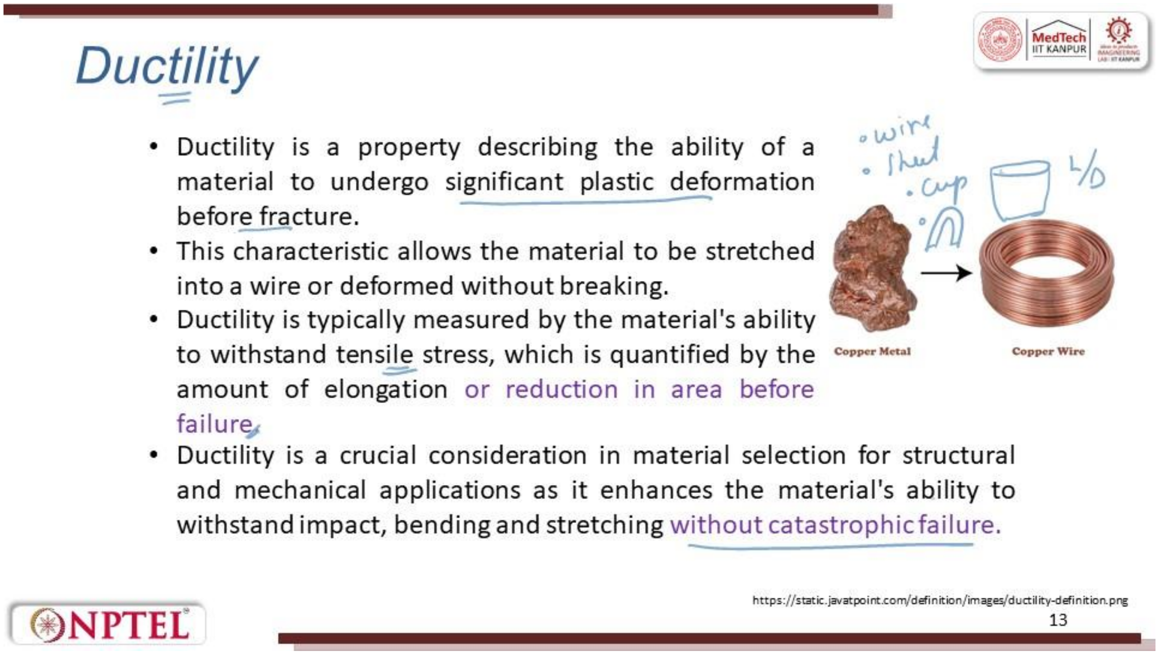


So, a tensile test when we do, many a times for a glass we never do a dog bone sample, for metals yes we do. So, these are the stages wherein which you can see the elongation. So, this is the elastic region and then you have the yield, from yield you go to ultimate to fracture.

So, necking starts at ultimate. After that it leads to fracture. This is for a typical metal. You see this response. When we try to this region of plastic strain, it is reduced to a large extent.

And here you see the elastic deformation will happen. Here uniform plastic deformation will happen. Uniform plastic. And here it is non-uniform. So it can happen immediately.

It can even happen here and the slope can go like this. So, it is non-uniform. So, we always try to plan here or we will plan here.



Let us move to Ductility. Ductility is a property describing the ability of a material to undergo significant plastic deformation before fracture, making of a wire making of a sheet, making of a cup which has a high aspect ratio.

So, what is aspect ratio? L by D. So, length by diameter, right? So, we try to look into it. So, for example, you started with a sheet and then you did. Then, when we are trying to bend for a hairpin, for a gem clip.

So, all these things are made out of gem clip. So, all these things are made from a metal wherein which there is ductility property. Ductility is a property describing the ability of a material to undergo significant plastic deformation. This characteristic allows the material to be stretched into a wire or deformed without breaking. Ductility is typically measured by material's ability to withstand tensile stress which is qualified by the amount of elongation or reduction in the area of the failure.

Ductility is a crucial consideration in material selection for structural and mechanical application as it enhances the materials ability to withstand impact, bending, stretching without catastrophic failure.

Characteristics of Ductility

- **High Plastic Deformation:** Can stretch and bend significantly before breaking.
- **High Toughness:** Absorbs and dissipates energy, resisting impacts and shocks.
- **Good Tensile Strength:** Withstands significant tensile stress and elongates under load.
- **Moderate to High Ductility:** Exhibits substantial elongation or reduction in area during tensile testing.
- **Stress Redistribution:** Redistributes stress around notches and cracks, preventing sudden failure.

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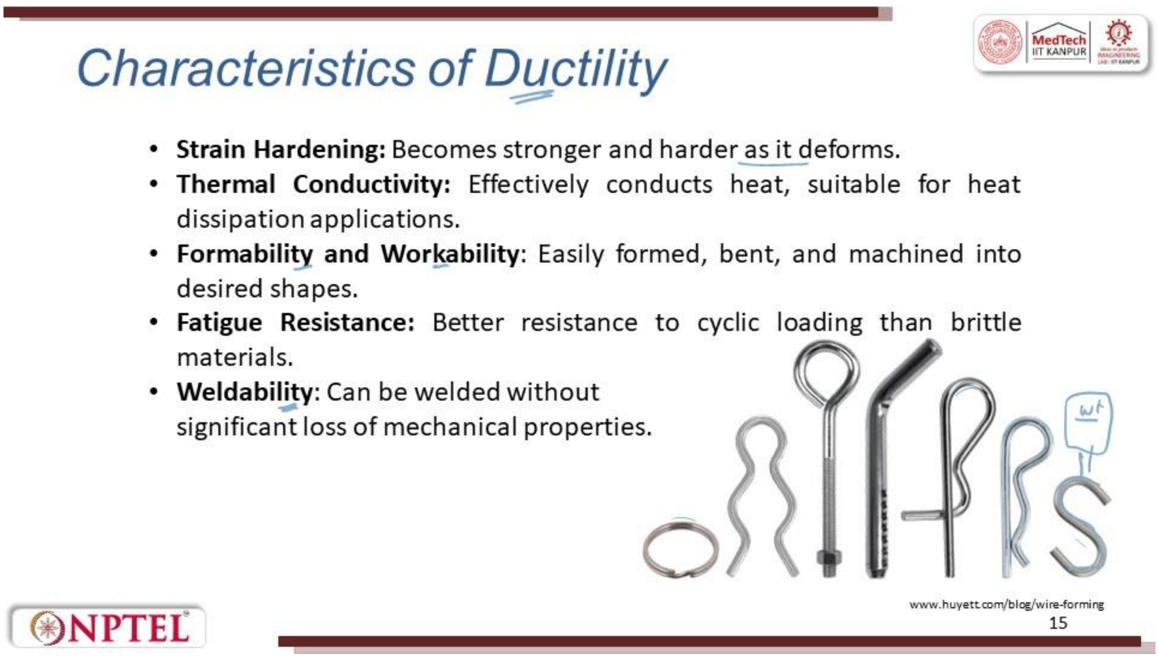
Characteristics of ductility, High Plastic Deformation can happen, can stretch and bend significantly before break. High toughness, so it absorbs and dissipates energy, resisting impact and shock. For example, a guitar string, you keep playing. Guitar string, sometimes you play it at high frequency.

When your hand moves up and down, up and down, high frequency, amplitude is very low. When you try to travel in a bus, passengers getting up or getting down the bus, a lot of absorption is there. When the bus tries to hit another surface, then it is absorption. When we try to hit a rod which is there in the bus with your bag, it is absorption and dissipation of energy. When we are trying to do cooking using a utensil, then there is a lot of shock, a lot of absorption and a lot of dissipation of energy.

So when you drop a spoon from a certain height, it's absorption and dissipation. Good Tensile Strength withstands significant tensile strength and elongates under load. Moderate to very High Ductility there exhibits sustainable substantial elongation and reduction. Reduced Stress Distribution, redistribution stress around the notch and crack prevents the sudden failure to happen. So these are some of the examples you see here.

You can make a ring. You can make a hairpin. This is a bolt which is made. You can make a nut. These are different angular clips.

These are S hooks which are used to hold or this S type hooks are used even for spring balance where in which the weight is measured. Today when you go to small vendors, they have this digital display S type which can measure up to 3 kilos.



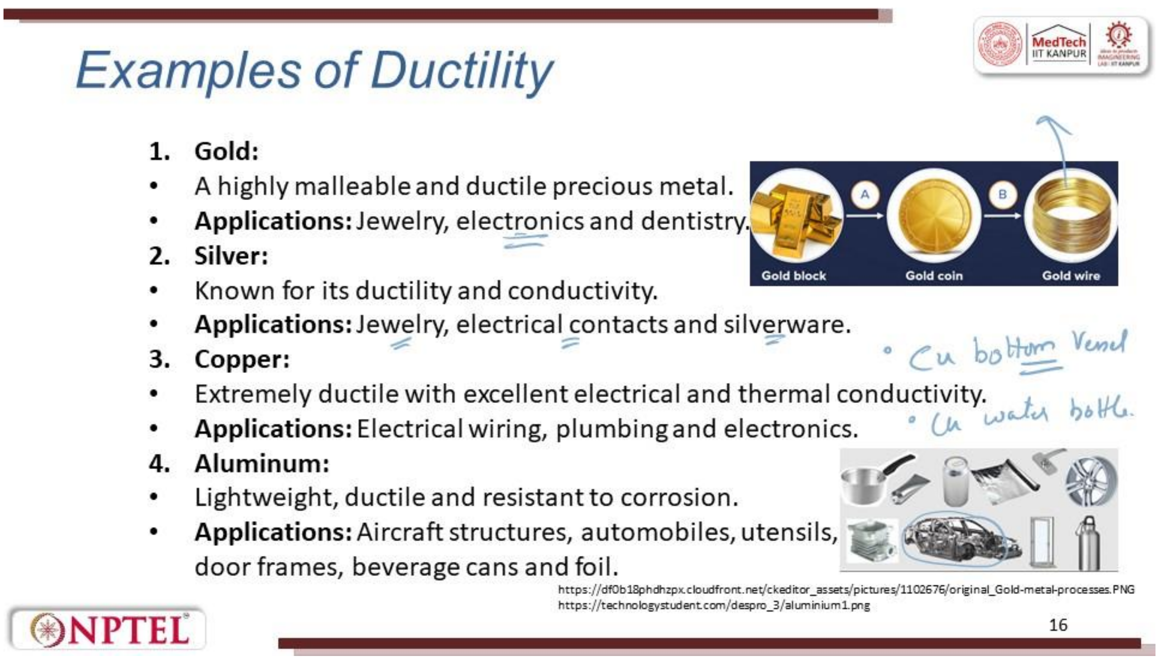
Strain hardening becomes stronger and harder as it deforms. Then thermal conductivity is also part of it. When we try to look at many of the ceramic materials, brittle materials, they are all non-conductive.

So thermal conductivity effectively conducts heat, electricity, suitable for heat dissipation application, formability and workability, easily formed, bent and machined into a desired shape. Ceramics machining is very very difficult. Giving a shape to ceramic is very difficult. Generally what we do is we try to take ceramic, take even pottery. We try to have clay, we try to give a shape to it and then after it is given a proper shape then we go for baking.

When we go for baking, all the bond, whatever it is there, it gets converted into ionic bond. So, this ionic bond makes the ceramic harder. When we are trying to work with metals, it tries to give us this flexibility because it has a property of ductility. When you are drilling a hole, there is a huge impact load which comes through the tool on the workpiece. Now, when it starts machining, there will be a huge load.

All this load gets redistributed. So, the metal does not get distributed. Whereas when you keep a ceramic, when you start drilling it, it just fractures. So Fatigue Resistance for a metal is always high. Better resistance to cyclic loading than brittle fracture.

For example, this hairpin clip, you can release, load it, unload it, roll it, no problem. The wires which are used for electrification, the copper wire which is there, you can bend it to any shape to meet out the requirements. Weldability can be welded. Weldability is a property wherein which the metals can be used for joining. Dissimilar metals joining can happen that's because of the ductility property.



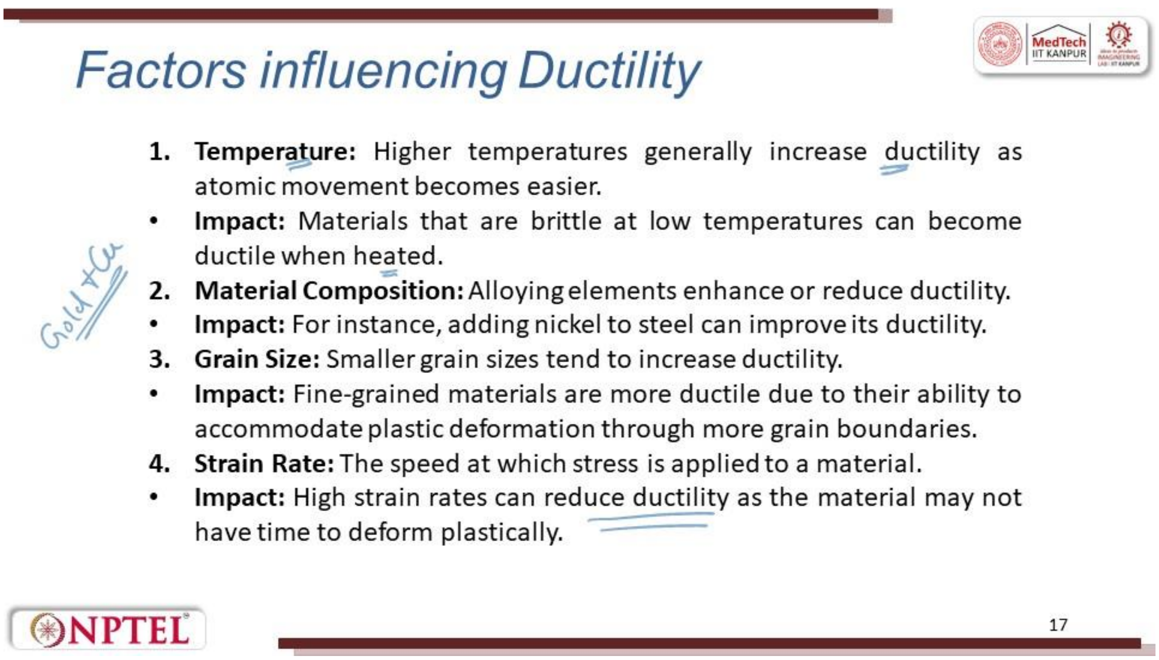
So, some of the examples for ductility, you will see gold, highly malleable and ductile precision metal. You can see gold block leading to a gold coin from a gold coin leading to a gold wire, which can be used for engineering application or ornamental application, jewelry, electronic and design. Electronic industry also used gold wire. Then dentistry also people are using gold wires. Silver, known for its ductility and conductivity, used for jewelry, electrical contacts and silver wires.

Copper, extremely ductile and excellent electrical and thermal conductivity. That is why we use copper bottom vessel in cooking. We also use, it also have medicinal values. We have copper water bottles today. Extremely ductile with excellent electrical and thermal conductivity.

Application is electrical wiring, plumbing and electronics are there. Next is aluminium, lightweight, ductile and resistance to corrosion. So these are the other thing aluminum which is also used in utensils. Utensils are made out of aluminum. Wheel rim is made out of aluminum.

Bottles are made out of aluminum. This is called as White Body part of a car which is also made out of aluminum. Lightweight, ductile and resistance to corrosion. Today we are replacing it with titanium. It is expensive.

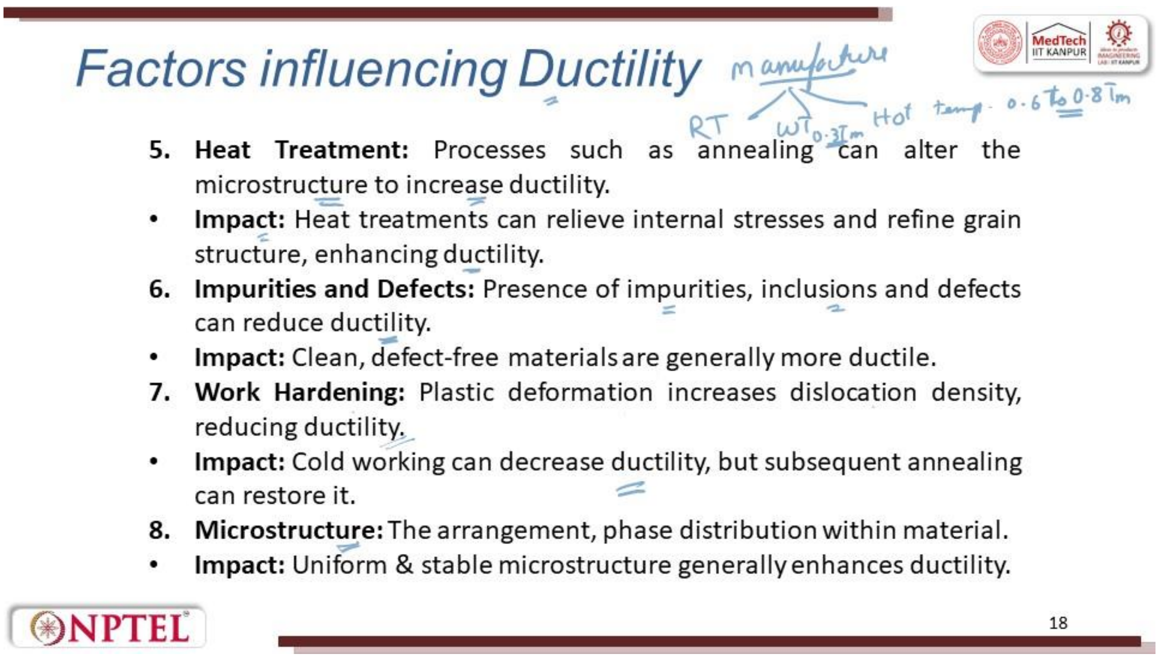
Still aluminum plays a very very important role. Application, aircraft structure, automobile, utensils, door frames, beverage can, the coke can, whatever you drink, it's made out of aluminium and foils.



The factors influencing ductility, Temperature plays a very important role in ductility. By increasing the temperature, you can increase the ductility. That's why what we do is we always try to take a material to a higher temperature and deform much faster.

The atomic movement becomes easy. Impact, material that are brittle at low temperatures can become ductile when heated. Material composition, alloying elements enhances or reduces ductility. So, basically gold alone does not have so much of ductility, but when you mix it with copper, it has strength and malleability coming together. Next is grain size.

Smaller grain size tries to increase the ductility. Impact is fine grain material are more ductile due to their ability to accommodate plastic deformation through more grain boundaries. Strain rates, the speed at which the stress is applied to a material, high strain rates can reduce the ductility. For example, if you try to take a rubber band, instantly pull it at a very high speed for a long elongation, it shatters. But slowly if you do it, even for a large distance, there is not much of plastic deformation getting introduced.



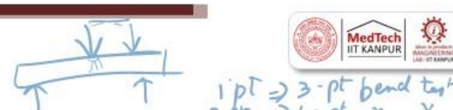
Heat Treatment, the process such as annealing can alter the microstructure to increase ductility. Its impact is heat treatment can relieve internal stresses and refine grain structure, enhancing the ductility. Impurities and Defects, the impurities, inclusion and defects can reduce ductility. So the impact is clean defect free materials are generally used. Work hardening which is also by applying heat you try to deform.

Plastic deformation increases dislocation density, reduces the ductility. So, cold working can reduce ductility. That is why we always try to do heat treatment. So, generally in manufacturing or especially in rolling, we have three things. One is called as room temperature deformation, warm temperature deformation and hot temperature deformation.

So, room temperature is room temperature. Almost three times the Tm we go for warm heat treatment. 0.1 to 0.3 times the Tm. Hot is somewhere close to 0.6 to 0.8 Tm. We try to go.

Again it differs from material to material, so by changing the temperature what we do is we try to change the microstructure, we try to reduce the work hardening have more ductility for your output. So this can mean that if you are trying to make a chair or make a bucket or make a utensil you can draw it for long. So that means to say the depth can be longer. The depth of the vessel can be longer. The microstructure, the arrangement phase distribution within the material can happen which also influences the ductility. Uniform and stable microstructure generally enhances the ductility.

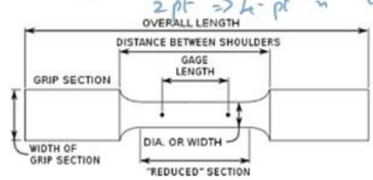
Testing for Ductility

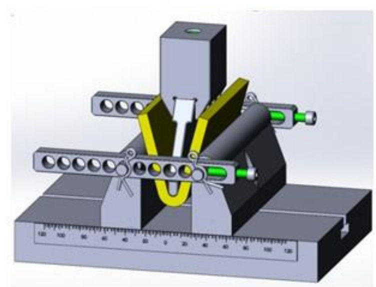


We can conduct various direct or indirect tests to understand ductile behaviour of a material.

1. **Tensile Test:** A standard test where a specimen is subjected to uniaxial tensile force until failure.
2. **Bend Test:** A test where a material sample is bent to a specific angle or until it fractures.

- **Procedure:** The specimen is placed on supports and a force is applied at the midpoint to bend it.
- **Output:** Observes the material's ability to undergo plastic deformation without fracture indicating its ductility.





www.victortestingmachine.com/tensile-test-procedures/
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The Test for Ductility. The test for ductility can be performed many ways. This is a typical dog bone sample. You can do a tensile test and get the stress strain response area under the curve, also you can try to talk about the ductility.

The Tensile Test is one. Standard test used in a specimen which is subjected to uniaxial tensile force until failure. You can get the ductility. You can also do a bend test. Bend test is nothing but you try to have two loads at the bottom and then you apply a single load at the top.

So, this is called as three-point bend test or a bend test. A test where material sample is bent to a specific angle or until it fractures is called as bend test. The procedure is going to be the specimen is placed on your support. These are the supports, right. And your force is applied at the midpoint to do it.

You can have single point. You can also have two points. So, this is a single point. It is called as three point bend test. When it is two point on the top, right.

It is called as four-point bend test. In ceramic material, nowadays we try to do four-point bend test because now the load is distributed over an area, you get a better response as compared to that of a three-point bend test. In the three-point bend test, suppose by chance if the place where you keep the load has some defect, then that helps in propagation very fast. In order to get out of that situation, we move to four-point bend test. So the supports can be adjusted depending upon your bend angle and depending upon the depth whatever you have to give.

So that is the choice for every material. There is a different bend response or angle. From there you can try to find out what is the response for ductility. Output test observed that the material's ability to undergo plastic deformation without fracture indicates its ductility.

Testing for Ductility

3. **Fracture Toughness Test:** Measures the ability of a material with a crack to resist fracture.
- **Procedure:** A pre-cracked specimen is subjected to tensile stress and the stress intensity factor is measured at point of crack propagation.
- **Output:** Higher fracture toughness values indicate better ductility.
4. **Creep Test:** Measures the long-term deformation of a material under constant stress at elevated temperatures.
- **Procedure:** A constant load is applied to a specimen at a specific temperature and the deformation is measured over time.
- **Output:** Materials that show significant deformation before rupture are considered more ductile.

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Fracture Toughness is another test which we conduct for finding out the ductility. Measures the ability of a material with a crack to resist fracture also we can try to find out. You remember ISAT test we saw Charpy test. From there also we can try to do.

A pre-cracked specimen is subjected to a tensile stress and a stress intensity factor is measured at a point of the crack propagation fracture toughness. The output higher fracture toughness values indicate better ductility.

Creep test is also used. Creep test is long term deformation of a material under a constant stress at elevated temperature. At a certain higher temperature, constant stress for a longer time. So the procedure, a constant load is applied to a specimen at a specific temperature and the deformation is measured over time. Output materials that show significant deformation before rupture are considered more ductile.

Case Study: Brittle Failure Liberty Ships

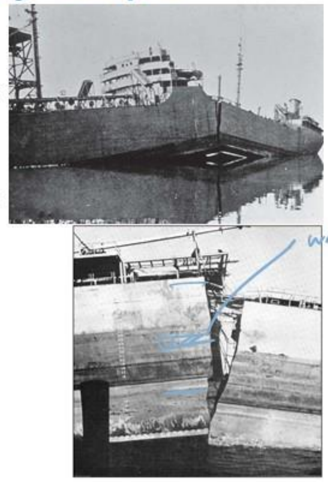
Background:

- **Context:** Liberty ships were mass-produced during World War II using welded steel plates for rapid and economical construction.
- **Incident:** Several ships experienced catastrophic brittle failures, often breaking in half, especially in colder waters.

Factors Contributing to Brittle Failure:

1. **Material Properties:**

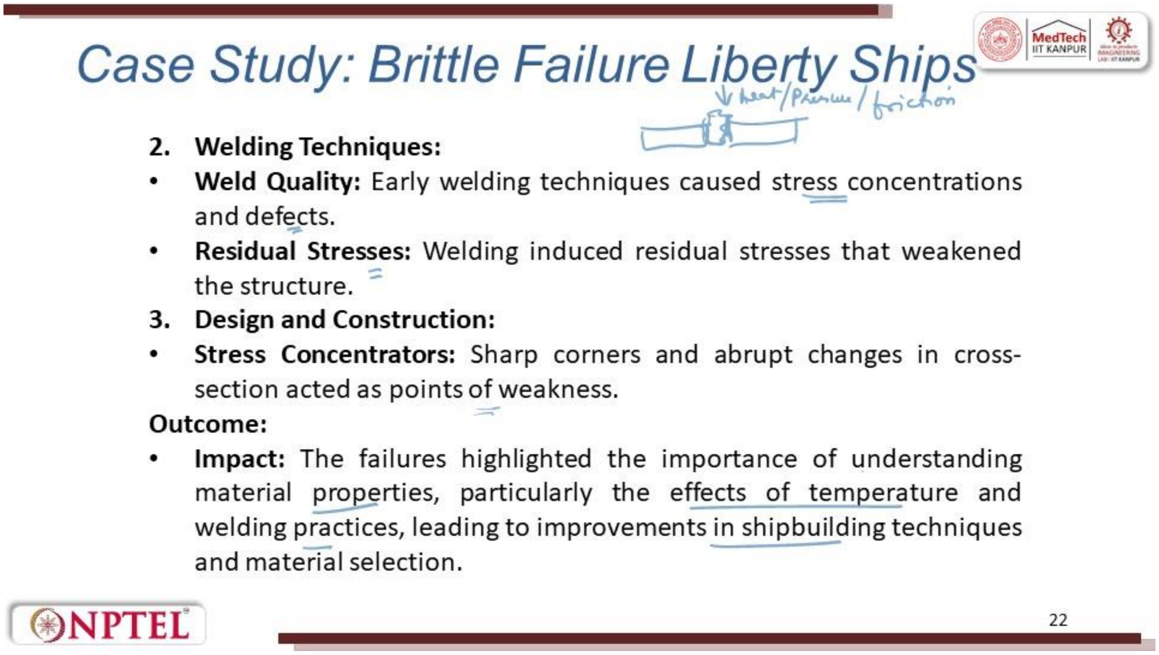
- **Steel Composition:** High carbon content and impurities increased brittleness.
- **Low Temperature:** Steel became more brittle and less tough in cold environments.



https://metallurgyandmaterials.wordpress.com/wp-content/uploads/2015/12/liberty-ship-failure.jpg?w=640
www.mdpi.com/challenges/challenges-07-00020/article_deploy/html/images/challenges-07-00020-g001-550.jpg

Let us now see two case studies. Brittle fracture which happened in the Liberty ship. Background. Liberty ship were mass produced during the World War II using welded steel plates for rapid and economic construction. They could not deform. A lot of depth cannot be done.

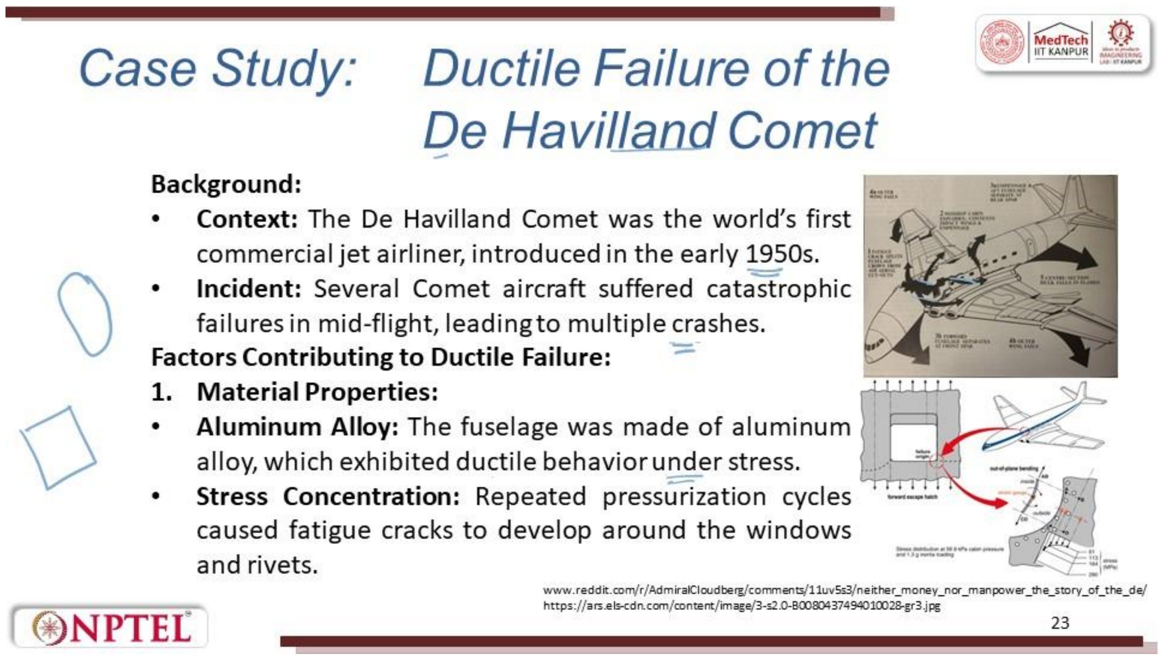
So what they do is they do it as piecewise and these pieces were joined by welding. So Incident, several ship experienced catastrophic brittle fracture often breaking in half especially in cold water. The factors contributing to brittle fracture are material properties, steel composition, high carbon content and impurities increased brittleness. Low temperature, the steel became more brittle at low and less tough in cold environment. Cold environment means in minus temperature.



The Welding Technique, the Welding Quality; early welding technique caused stress concentration and defects and it introduced residual stress. The welding introduced Residual Stress. Why Residual Stress? Because in welding what you do is you apply heat. In welding, you always apply, you want to pour a material here.

How do you pour a material? You apply heat here. Heat, it can be heat, it can be pressure, it can be friction. So, heat is one place where you apply. So, that always leads to welding.

So, when we apply heat, there is a non-uniform shrinking. The welding induced residual stress that weakened the structure, the residual stresses are introduced. The design and construction of the stress concentrators, sharp corners and abrupt change in cross section acted as point of weakness. The outcome is the failure highlight the importance of understanding material property, particularly the effect of temperature, welding practices leading to improvement in the ship building technique and material selection.



Let us look at the other thing which is other case study which is ductile fracture of the De Havilland comet. This is a plane. So the context is the Comet was the world's first commercial jet airlines introduced in the early 1950s.

Incident, several Comet aircraft suffered catastrophic failure in mid-flight leading to multiple crashes. So it is here. These are all, so if you see here, it is like this.

So, the factors contributing to brittle fracture, material property, aluminium alloy, the fused sludge was made out of aluminium alloy which exhibits ductile behaviour under stress. The stress concentration, repeated pressurization cycle caused fatigue cracks to develop around the window and rivets. So earlier the windows were square. If you now travel and see, it is always like this. So repeated pressurization cycles.

So, when you get into the plane, there will be a pressure which is applied. Repeated pressurization cycles cause fatigue cracks to develop around the windows and rivets which are used for joining.

Case Study: Ductile Failure of the De Havilland Comet

2. **Design Flaws:**
- **Square Windows:** The square design of the windows created stress concentrations at the corners, exacerbating crack propagation.
- **Structural Fatigue:** Continuous pressurization and depressurization cycles led to metal fatigue, a form of ductile failure.

Outcome:
- **Impact:** The investigation into the Comet disasters led to significant improvements in aircraft design, such as the use of rounded windows and better understanding of metal fatigue. These changes enhanced the safety and reliability of future aircraft.

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The Design Flaw: Square Windows. The square design of the window created stress concentrations at the corners, exacerbating crack propagation. The Structural Fatigue, the continuous pressurization and depressurization cycle led to metal fatigue and form of ductile fracture.

The outcome is the investigation into the comet disaster led to significant improvement in aircraft design such as to use rounded windows and better understanding of metal fatigue. These changes enhanced the safety and reliability of future aircrafts.

To Recapitulate

• Ceramics → make hole in the panel using a hot rod held in hand
• Polymer → shape of hole during drilling & after drill

- What is brittleness and how does it differ from ductility in materials?
- Provide examples of materials known for their brittleness. Also state their applications. • Wire/bend and create a Freeform Shape
- Why is brittleness considered a disadvantage in certain engineering applications?
- What are the key factors influencing the brittleness of materials?
- Discuss testing methods used to determine the brittleness of materials.
- Define ductility and its importance in material selection for structural components.
- Give examples of ductile materials and explain why they are preferred in certain applications.
- What are the main factors influencing the ductility of materials?
- Compare and contrast the mechanical properties of brittle and ductile materials.
- How engineers enhance the ductility of materials through design and alloying?

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So, in this lecture, we saw what is brittleness, how does it differ from ductility. We provided some examples for brittleness. Brittleness considered a disadvantage in certain engineering applications.

Key factors affecting or influencing brittleness. What is the test which is used for brittleness? From there we moved towards ductility, understood different examples in ductility and found out the influence factors, the main factors influencing ductility. We compared brittleness and ductility. Finally, we saw how does this ductility and brittleness help in engineering design.

So today, do it by yourself. I have two exercises. The first exercise is going to be try to take a glass window or glass and try to make a hole in the glass panel using a hot rod which is held in hand of you hot rod which you try to like a soldering rod, hot rod, you try to make a hole. So that will be first exercise, you will try to see what is the response which is happening around it. The next one is take a polymer sheet and try to repeat the same exercise.

Try to record the shape of the hole during drilling in plastic material and after drilling. Here you will see the concept of temperature introduced residual stresses and how does it help in deforming the ship. The thermal conductivity and expansion plays a very important role. The third point is going to be try to take a rod. A plastic wire, I would say plastic wire in the sense where in which you have little bit of stiffness.

Try to bend and create a free form shape. Any shape, a very small plate or a table coaster, you can try to make a very small one and try to see when you try to bend what happens to it, when you try to bend and lock what happens to it and finally how do you get it. So, when you do these three exercises, you will truly start appreciating the influence of material with respect to ductility and brittleness.

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These are the references which we have used in generating the slides.

And thank you so much.