

Manufacturing of Composites
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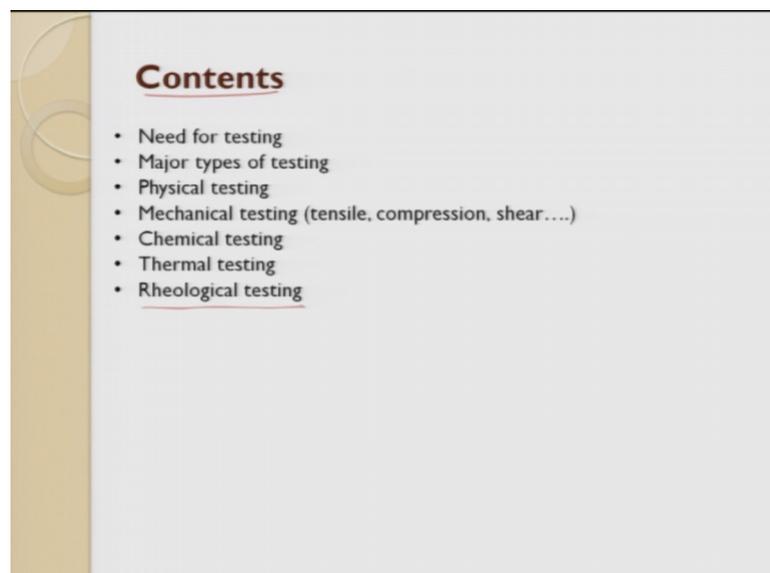
Lecture - 05
Composites Testing

Well friends, let us move to lecture 5. Lecture 5 is on composites testing. So, a composite testing is very important and it is also very different. So, by this time you should be able to appreciate that the composite does not fail like a homogeneous material. For example; it does not fail like aluminum failure, aluminum alloy failure.

Generally, when I say homogeneous metal, now, no pure metal has engineering applications; it always means that there is an alloy. I told you the difference between alloy and the composite, now in composite you have a matrix which is soft, reinforcement which is tough, which has very high strength and the interface between these two plays a very important role. Now, you have three parts playing a role for complete material. Composite testing is very important.

And in composites I stress here, that there is nothing called as a full failure of a composite. The polymer fails, the reinforcement takes over, the reinforcing keeps continuing for some more time and it goes on like that. The elongation keeps continuing, so, it is not a proper fracture.

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Contents	
•	Need for testing
•	Major types of testing
•	Physical testing
•	Mechanical testing (tensile, compression, shear....)
•	Chemical testing
•	Thermal testing
•	<u>Rheological testing</u>

So, here we would like to, content of the slide we would like to see; need for testing, what are the different major types of testing, we cannot cover all the testing, I have just picked major. In this major you have classifications like physical testing, mechanical testing, chemical testing, thermal testing and rheological testing.

So, the rheological testing is more focused towards the polymer. How does it gel when does it gel what is the time and during the gellation time, how should I understand, what should I do, all these things are more discussed about rheology and why rheology, polymer is a visco elastic material. So, the property changes with respect to time and temperature that is what is rheology. And nondestructive testing, we are not covering right now. Towards the end of the course we will have, repair and non destructive testing, there we will talk about non destructive testing in length.

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Need for testing *minimum of 5/7*

- Composites final properties are dependent upon chemical reactions (unlike metals)
- fabricator cures the part, methods must be used to control fabrication
- Careful testing, evaluation and control of manufacturing characteristics are necessary to ensure that final-part structural performance is obtained.

Diagram 1: Stress-Strain graph showing curves for Fib, comp, and mat. The y-axis is labeled 'Stress' and the x-axis is labeled 'Strain'. The 'Fib' curve is the steepest, followed by 'comp', and 'mat' is the least steep. A point 'I' is marked on the 'comp' curve.

Diagram 2: Cross-section of a composite showing 'interphase', 'reinforcement', and 'matrix' layers.

Need for testing: the composite materials are dependent upon chemical reaction, why because; the polymer is used as a matrix. This matrix, when you add hardener and other ingredients, it tries to set. Suppose, if the matrix is not set properly because of improper additives which you add and if it also has a poor interface, then you might see outside, the composite might look proper; that means, to say it will be something like a core and shell. So, core is the reinforcement and this is the inter phase and this is the matrix. If the interface is not properly formed, though the composite might look good, but it will underperform when it is put in real time use.

There is always a careful testing required and it is not easy like metals. Here, you are supposed to properly grip and then conduct your evaluation properly. And I advice that, whenever you want to do testing, please do minimum of 5 to 7 samples to really understand the phenomenon, because matrix failure there will be a jump. Whatever is drawn schematically, we say that this is the fiber response, this is the matrix response, and this is the composite response we say, but, here it is all, this is stress versus strain. This is what, it is a theoretical one. In reality, you will have lot of kink in your structures and you can also have a premature failure. It is always advisable to minimum do 5 to 7 test of whatever sample testing you do as for as composite is concerned. Then what happens, you can try to have a mean and error for every point whatever it is.

Careful testing, evaluation and this is very important because this leads to control manufacturing characteristics are necessary to ensure that final part structural performance is obtained. There are basically 3 types of testing; one is called as mechanical testing, the other one is called as chemical testing, the third one is called as polymer testing. Why polymer, why thermal testing, because polymer tries to degrade, degradation.

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Major types of testing

- mechanical ✓
- chemical and ✓ → etch the matrix
- thermal testing ✓ → Polymer - degradation → Service Condition temp/humid

Stages at which testing is done:

- ✓ Supplier: runs a battery of physical, chemical and mechanical property tests before shipping the material — cat log / information sheet
- ✓ Fabricator: receives the material, same tests are often repeated.

After the part is fabricated, the part is normally subjected to nondestructive testing

So, we are supposed to find out, what should be the service condition we are trying to use the product. Service condition means temperature and humidity as far as polymer composite is concerned. Chemical testing, because it should not etch the matrix. Moment

it starts to etch the matrix, reinforcing cannot do anything. The testing can be divided into mechanical testing, chemical testing and thermal testing.

There are several stages at which the testing is done. It will be done, first test will be done by the suppliers, because he gives you a sheet, catalog sheet wherein which, he tries to say that, this is what is the property my sample will produce or this is what is the performance this will produce. So, they have supplier data will be there. He runs a battery of physical, chemical, mechanical testing and then he gives you a catalog or he gives you a pamphlet or a sheet, information sheet he gives wherein which, he tries to put all the data where his sample will work safe. And today, the suppliers have become more careful, because they would like to give only realistic data. They do not over claim, because if a composite fails, with these suppliers can be questioned.

After the suppliers gives, the suppliers gives only raw material, the fabricator tries to add ingredients and tries to produce. Then the fabricator also runs the similar test after fabricating a component. He tries to makes sure; when it is given to the customer it is working to its satisfaction. After the part is fabricated, the part is normally subject to nondestructive testing only.

Why because, destructive testing can be done for a test coupon, destructive test with the life product is a costly episode, because it in a live product the simulating condition it is very difficult to do and once you simulate with multiple loads acting on a product, kept on top of you are developed products, so, simultaneously running the simulation, recording the data is a challenge. That is why we always go for non destructive testing, if you take automobile engineering; in automobile engineering they do a crash test. The crash test is done only at the design stage, recording all the crash test data is a big challenge. So, in automobiles composites are exhaustively used.

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Physical testing

- Compression Molding ✓
- Determination of Glass Fiber Content ✓ V_f linked $W_f \sim \rho$
- Determination of Gel Time of a Thermosetting Resin
- Determination of Viscosity of a Thermosetting Resin

viscosity change
liquid gel solid

So, as far as physical testing is concerned, there is compression mold, molding is done. Then we try to do the fiber volume fraction, you remember, we talked about V_f , it is in turn linked with W_f , this in turn is linked with the density of the composite. Determination of the fiber volume content and here all our testing is more focused towards only polymer; then determination of gelling time for a thermosetting resin, determination of viscosity for a thermosetting resin.

The gelling time, what is gelling time. Gelling time means a liquid is getting converted is slowly moving to a solid. It is getting into a term, in between the term called as gelling. So, what happens, the viscosity changes, from liquid low viscous it goes to high viscous. It is good to know, what time the gellation starts and once it starts forming, how does the viscosity change such that, I can use the same polymer to make a sound product with reinforcement.

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Mechanical Testing

- tensile, ✓
- compressive,
- flexural,
- torsional, and
- shear.

Composite - fiber
- interphase
- orientation
- laminae

All of the force types are important to determine the behavior of composites in different circumstances.

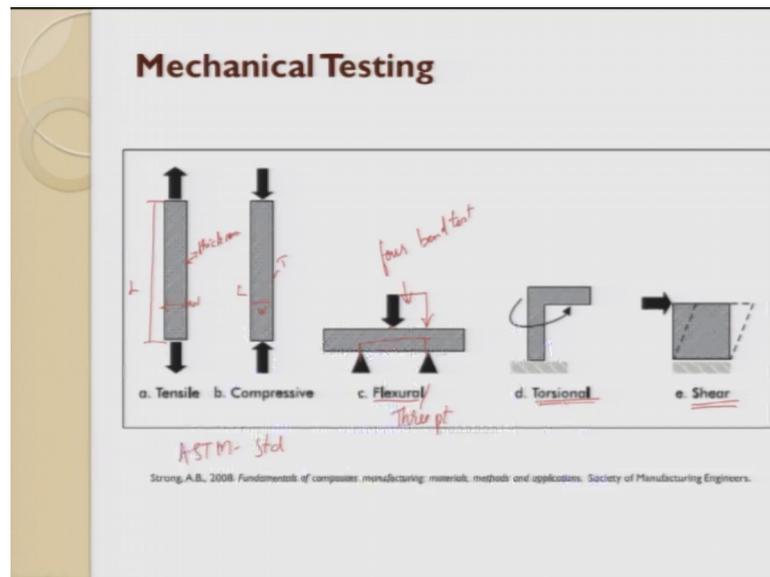
↳ no single loading happens when product is put in usage

Mechanical testing: the most common and exhaustively used testing is, tensile testing. Other tests are generally avoided for a homogeneous material, because, there is a direct link between the tensile and compression, or a period of time; there are data base, data books which tell that there is a ratio available.

But as far as composite is concerned, we have fibers, we have inter phase and we have orientation all this and then these are in laminae are there. These are the variations which bring in; so that, in a composite, we are supposed to do almost all these test to talk about the aim product. Tensile is most commonly used, we will also use. In homogeneous metal, there is a relationship between tensile compressions, tensile flexural, tensile torsion is also possible and tensile shear is also possible. But here, in composites every test is conducted to get a sound product.

So, all the forces types are important to determine the behavior of the composite in various circumstances. As I said, there is no single load loading happens, when a product is put in good use. When a product is put in usage there is no single load there will always be multiple loads, the weight age of each loads also changes. So, this is why it is important to do all the test.

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So, this is tensile, basically you try to hold the sample and there are several ASTM standards, which are to be followed, to find out what is the width and what should be the length and what should be the thickness. All these things are to be found out. So, there are some ASTM standards, depending upon the requirements, you can keep changing the ratio of L versus W versus T and then we start doing the test. Same way you can also do compression. Compression is generally, it is a schematic diagram; the sample size will be less.

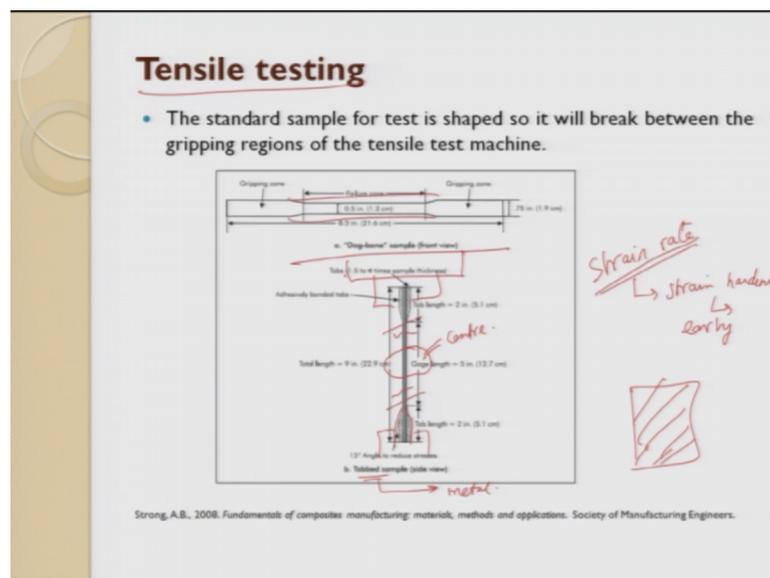
Again here, there is a ratio of W , L and T . We generally try to avoid compression; we do a flexural test which is called as a three-point bend test, flexural or a three-point bend test. So, in a three-point bend test, what we do is, we try to distribute the load between the two- points and then we apply a load. We can also use three-point bend test. Today, there is also called as four-point bend test, because in ceramics what happens if you apply load on one centre and if at all there is a crack, the crack propagates very fast and it shatters.

So, now people have said that it is advisable to use four- point bend test, as far as ceramic matrix composites. Polymer matrix composite we can always go for a three-point bend test. This is a torsion test is also used. Torsion is done for a tube; torsion is done for such components. We also do a shear test; shear test or a pill test is carried out, so that, we try to understand what is the inter-laminar shear strength between the 2

laminae. This all the three are there, generally there will be different combinations of these loads getting acted. It is important to understand everything and then do. How do we make sure our product has different conditions or our products load we do not know, how do you make sure in the design stage that we assume certain specification and start doing.

So, generally what we do is, we have a term called as factor of safety. We add a factor of safety 2 times, 4 times or 1.5 times, we try to make sure the loads cannot be more than this and according to the higher load we start manufacturing the component. Factor of safety is very important. Can I be very liberal giving factor of safety? If you be very liberal and giving factor of safety basically what are you trying to do you are trying to tweak your design for a higher factor of safety, you will basically add more weight to the end product. So, it is better to have a proper choice of factor of safety.

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Let us get into tensile test. The tensile test, what we do is, we try to make something like a dog bone sample or what we do is we even make flat samples depending upon the ASTM standards given.

We try to take these 2 and generally what happens, when the ends of the composite are directly held between grips, there is a possibility that if you use a thermoset polymer and your gripping is very tight, the crushing of ends starts very fast and if you do not grip properly, you can see a failure happening here, a failure happening here or a failure

happening in this points. Generally, the failure has to happen very close to the centre. So, for this to avoid what we do is, we always put something called as tabs. These tabs are made out of metals, tabbed sample. So, these are made out of metal; these metals tabs are stuck by using very strong adhesive and then we try to clamp it between grippers. Before even tabbing it, people try to do a small grooving, trying to introduce some friction on top of the composite, so that, the metals can get adhere to it very good. So, this is done and then this is held between grips and then we try to operate it at a one strain rate as per the ASTM standard and then slowly start doing it.

Today, there are lot of modules which have been which are getting added to this testing facility. So, they have something like a chamber which is attached which tries to bring in hygroscopicity in the sample or they also put a closed chamber and try to introduce temperature there. At varying temperature what is the response or at varying water content, what is the response, people start doing it.

One way of doing it is, you take the sample, put it inside an atmosphere, maintain at a humidity 60 percent, 70 percent, 80 percent and then come here do an ASTM standard the tensile testing. The other way round is, you start using simultaneously and then see also and also they try to do the testing of it. So, here this strain rates are important. Strain rates, if you choose a improper strain rate, then you will have strain hardening happening very fast. This strain hardening will lead to early failure, so a proper choice of strain harden straining rate; that means to say pulling rate, strain rate is very important.

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Tensile testing

$\sigma = F/A = N/mm^2$

- The force divided by the area is called the stress.
- So that materials of different sizes can be directly compared, the force
- is usually divided by the area of the sample, yielding units of pounds per square inch or pascals (newtons per square meter).
- The elongation is a measure of the strain when the force is tension.
- Elongation is usually expressed as a percentage increase in length compared to the original length of the test specimen.

• Uniaxial testing test
• Biaxial test

Force
displacement
strain

Strong, A.B., 2008. Fundamentals of composite manufacturing: materials, methods and applications. Society of Manufacturing Engineers.

The force divided by the area that is nothing, but stress equal to force by area. So, basically what comes out of this is, you get something called as a force versus displacement curves, you get a force versus displacement curve. So, this curve, generally machine gives this and today software technologies have come, wherein which it converts this into stress and strain and then it gives you the data straight. The force divided by area is nothing, but the stress. For a material of different size, can be directly compared by the force is usually divided by the area of the sample yielding units per pound or whatever. So, we always what is a unit of is Newton per millimeter square or something. That is the stress.

Elongation is strain; strain is a unit less quantity. It is percentage of elongation, we generally talk about, it tries to talk about what is the displacement you get for this. Elongation is expressed in terms of percentage you get the output. Today, what has happened till now? We have been happily using only uniaxial tensile testing. So that means, to say a sample at one direction you try to do.

Today, there is a concept called as biaxial testing. So, biaxial testing is nothing, is you try to take like this. Biaxial testing is new phenomenon, wherein which, the loads are applied in one direction as well as in the 90 degrees in the other direction. New machines are getting developed; this is a concept which people are talking, because people realize that biaxial testing results are more reliable than the tensile testing.

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Tensile testing

The relationship between stress and strain :

$$\frac{F}{A} = \sigma = E\epsilon$$

where:

- F = force
- A = cross-sectional area
- σ = stress
- ϵ = strain
- E = proportionality factor, called the **modulus**, and sometimes referred to as **Young's modulus** for the tensile stress case.

The modulus is the slope of the stress-strain curve.

Elastic

Next tensile testing we give it in this thing. So, what we do is we try to get F by A is nothing but, stress; that is nothing, but E. E is the Young's modulus or modulus of elasticity and this is the strain. Generally, this modulus is done in the elastic region. We try to get the value of E and then this is predominantly used for strength calculation or this is used as a major factor.

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Compression Testing

- Compressive force yields information about the strength and stiffness of a columnar sample supported on its sides to prevent buckling when it is pressed on its ends.
- There are several methods for supporting compression test specimens and these have given rise to various test methods.
- Procedure consists of metal plates between which the tabbed sample is placed.
- In this case, the tabbing extends along both sides of the sample except for a small region (.50 in. [1.3 cm]) in the middle.
- The support fixture prevents the sample from buckling but does not prevent the non-tabbed region from failing.
- Pressure is applied only on the end of the sample..



Next is compressive test. Generally, we try to avoid doing compressive test for composites, but there are requirements. So, where we try to do for compressive forces

yield information about the strength and the stiffness of the column shaped support on the sides to prevent buckling when it is pressed on both sides.

We always try to take disc like components and if there is a necessity we also take a long aspect ratio component. There are several methods for supporting this compressive test specimen and this gives rise to various other tests. So, procedurally consists of a metal plate between the tabbed sample is placed and then in this case the tab extends along both directions of the sample except for a small range of this in the middle portion. I said tabbing is important for tensile, compressive also we do stopping and then support fixture prevents the sample from buckling, but it does not prevent from non tabbing regions, but also not prevents the non-tabbed region from failing; that means to say, you have a compressive, then you have a sleeve which is coming in and this is what we say it runs long. The pressure is applied on both sides and then we do a compressive test. Doing a compressive test very critically is very important. And if you do not do the proper procedure, then you might not get the required output; the output will be misleading.

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Compression Testing

The compressive properties can be quite different from the tensile properties because of the difference in the ability of the composite to support a columnar load versus a pulling load. *C* ✖

The fibers, in particular, have a tendency to buckle within the composite, especially when voids are present, and this greatly diminishes the compressive properties.

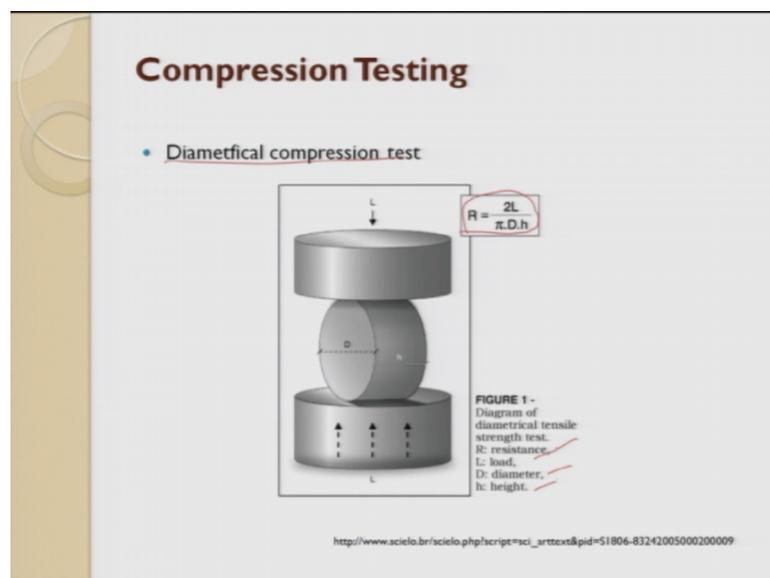
• Sound product - only should used for test

Compressive properties can be quite different from that of the tensile properties because of the difference in the ability of the composite to support a columnar load versus a pulling load. So, please understand, there is a big difference, this point is very important.

In generally, what happens is, composites are very good for tensile load, for compressive load, the reinforcement do not take that major load.

The fibers, in particular, have a tendency to buckle, because you keep pressing. Matrix shears within the composite, especially, when voids are present and this greatly diminishes the compressive property and one important thing you should all remember is, a sound product only should be used for testing. Suppose if there are voids, holes because of the processing difficulty, then they will try to yield very fast.

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Diametrically, if you want to do compressive test, this is what it is we follow. So, here is R which is given and these are the relationship. R is a resistance, L is the load, D is the diameter, h is the height.

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Flexural Testing

- The flexural or bending forces are determined by placing a rectangular sample across two supports and then pressing on the top of the sample.
- Most commonly the pressing is done with a single point of contact.
- This is called the standard flexural test or the three-point bend test.
- Occasionally, although rarely in composites, two points of pressure are used.
- When this is done, it is called the four-point bend test.

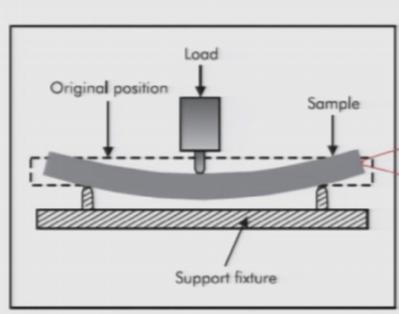


So, when I talk about the next thing is, flexural testing. Flexural testing is, I cannot make very long samples, because my product are very small. Generally, in thermoplastics what we do is, we try to do a flexural testing. Flexural testing or a bending force test, are determined by placing a rectangle sample. Basically, what we do is, we place a sample, we keep 2 supports here and we apply a load here; 2 supports and then plus a load. The most commonly used is single point, that is three-point bend; I also said it can be used for four-point bend also.

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Flexural Testing

Standard flexural test or the three-point bend test.



TP -> ductility
TS - ok

Strong, A.B., 2008. Fundamentals of composites manufacturing: materials, methods and applications. Society of Manufacturing Engineers.

So, this is what it is. We use support and here you should be careful for a thermoplastic sample you have lot of ductility. Three-point bend test when you use, you have to be little careful with the data. For a thermoset it is ok. You can use this data and you can get the required output.

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Shear Testing

- Shear testing is important for samples bonded by adhesives.
- Examples would be sandwich panels and certain joints.
- The most important of the tests for these materials view shear as a peel phenomenon (shearing along an adhesive plane).

Sandwich structures.

→ Core

Simple peel test

Strong, A.B., 2008. Fundamentals of composites manufacturing: materials, methods and applications. Society of Manufacturing Engineers.

The next one is called as the peel, is the shear test. Shear test what we do is, we try to take 2 laminates and then we try to see what is the adhesion strength between these 2. So, here what we do is, this testing setup is difficult, second things is the data which comes out of it has to be very minutely monitored. Preparing a test sample is also a very challenging job and this cannot be done after a full product is made; I peel it and then do it. This peeling has to be taken care right in the beginning itself, while you fabricate a component make sure that you are fabricating it only for this shear test.

Shear test is an important sample bonding by wherein which we study by adhesion. They would be sandwich panels of certain joints; for example, metal versus polymer CFRP, GFRP, polymer with a honeycomb structure. So, all these things there will be a core difference. In honeycomb structure or in sandwich structures, we have a top skin, bottom skin, this will be core. So, if you want to find out what is adhesion strength then we do this. The most important of the test of these materials view shear as the peel phenomenon. So, the shearing along the adhesion plane will be taken care.

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Peel Testing

- The climbing drum peel test measures the force required to peel a layer from a sandwich structure.

• Sensing interface is very difficult

Rolling drum peel test.

Strong, A.B., 2008. Fundamentals of composites manufacturing: materials, methods and applications. Society of Manufacturing Engineers.

So, this can be done for a plane and this is another test which is called as peel testing and here we tried to use a drum. You see a mounting fixture; there we see a sandwich panel which is kept here, a drum in the process of lifting the face of the sandwich panel. It will be something like a sticking and then peeling it off and when it peels off, the drum rolls all along. So, the drum rolls all along and here the top skin is peeled. A climb testing is also used, here it tries the sensing interface is very difficult.

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Impact/Toughness test

- The ability of a material to absorb energy without breaking (rupture) is called toughness. *→ low strain rate*
- It is related to the area under the stress-strain curve such as that developed when a tensile test is performed because energy absorption is the summation of all the force resistance effects within the system.

• High " → bulled fibre
→ Drop polymer test
→ Solid beam test

T_P + T_s ⇒ matrix ⇒ Hybrid matrix

- toughness*
- ductility*
- shrinkage min.*
- Ifact material is liquid form*
- viscosity ↓*

⇒ homogeneous

The impact and the toughness which is very important; impact is to find out what is a amount of energy which is absorbed. So, I wanted to mention today, the latest developments.

Today, people have started mixing thermoplastic and thermoset in the matrix. So, they are trying to take a blend of this 2, a hybrid matrix is formed, so that, it tries to take the toughness, ductility and they are trying to make shrinkage minimum and the starting materials is liquid form. What is advantage; the viscosity is very low for a liquid. Today, what is happened is, people have started doing, why because they want to enhance the toughness and the ductility together. Toughness means the energy absorbed; for example, today there are several composites which are made to take the impact load. Impact load is one common phenomenon which is there, when you put it in service condition; so ability of the material to absorb without rupturing or breaking.

Here, what do we do; we do even firing by a bullet, we use low strain rates, we use high strain rates, something like a bullet getting fired. We can also do a drop tower test; drop tower test: that means, to say you take to a very high altitude, drop from there or we can use a load bounce test. This is an impactor, we have a load of a certain height, we just drop and then find out what is the energy it can absorb. This can also be taken from a stress-strain curve, but generally for composites we try to do this drop tower test or the re-bounce test or bullet firing to find out what energy it can absorb. So, when you are trying to do sandwich structures the energy absorption is very important. Develop when the tensile test is performed, because the energy absorption is a summation of all the resistance within the system.

What they talk about is, suppose they have a curve coming like this, they say the area under the curve gives you the toughness. But this is good for homogeneous, but for composites this is not very much which is not very much reliable.

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Impact/Toughness test

- The toughness of a material is much more important when the force is applied suddenly in an impact rather than over a relatively long period of time, as is done in the stress-strain experiment.
- A property called **impact toughness** (sometimes called **impact strength**) is defined as the energy absorbed by a material upon sudden impact.

So, the toughness of a material is much more important when the forces are applied suddenly; that means, to say impact load. I said in a chair though people say compressive load is very important, but many a times what happens, people sit with 30 kilos, 40 kilos, 50 kilos they just sit with very high velocity. So, it is like more of impact rather than a compressive load. Suddenly an impact rather than over a relative long period of time as it is done in the stress strain curve. So, the property of impact toughness is or sometimes called as impact strength is very important test to be carried out and with this we try to get this data.

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Impact/Toughness test

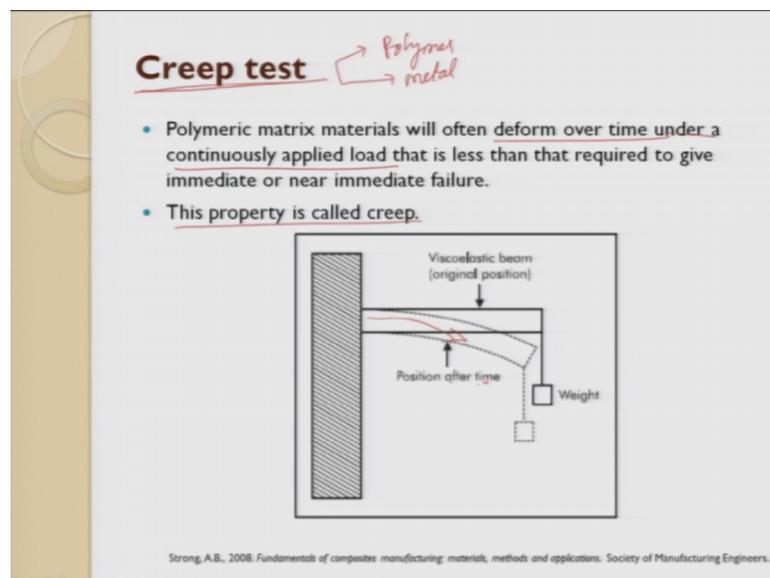
The diagram illustrates the components of an impact testing apparatus. At the top, a pendulum arm is shown with a 'Striking face' at its end and a 'Pointer' on its shaft. Below the pendulum is an 'Izod sample (in holder)'. To the left, a detailed view of an 'Izod sample' shows a rectangular block with a 'Notch' cut into its side. To the right, a 'Charpy holder' is shown holding a 'Charpy sample', which is a rectangular block with a V-shaped notch.

Izod and Charpy test

Strong, A.B., 2008. Fundamentals of composites manufacturing: materials, methods and applications. Society of Manufacturing Engineers.

It is generally done by 2 test; one is called as Izod, the other one is called as Charpy. So, this is Izod, where the composite is kept vertical. We make a notch; all this notch is only initiating a crack, please do understand. Here, what we do is, in a composite if at all you initiate a crack and these fibers are there, it is very easy to quickly grow the crack and then get the data, but you have to the sample preparation has to be done with utmost care. This is for a Charpy test and this is for Izod test. The notch is made, the orientation is different and the load we release a load and then see what is amount of toughness it can take, but more than this people start using the rebound test affect.

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The next one is creep test, since it has a polymer. So, we always go for a creep test if you have metals also people insist to use a creep test. Polymer matrix composite is often deform over time under a continuous applied load. For example; many a times we have in our garden, which is called we try to develop hanging garden. A pot will be attached with a thread and that will be attached to a hook or all of a sudden, the pot fails down and get shattered, it is why because, the polymer undergoes expansion.

So, this property is very important when you try to hang a load for a longer period of time, this test will try to reveal the value, such that, which can be used for applications. You see here, this polymer is a viscoelastic. Viscoelastic being original position, position after a period of time when the weight is applied you see it starts sagging down.

So, in the same way, polymer chairs also, over a period of time with the exposure to service conditions, the legs of a polymer chair yields and it is very dangerous, if a heavy load sits on it and if the chair is kept in open atmosphere for a longer period of time it can yield and the person might fall down. So, this property, if you want to have a proper understanding we do something called as a creep test.

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Creep test

- A load is applied over a long period of time causing the material to deform.
- When the load is removed, a small amount of the deformation will be immediately recovered (the elastic or short-range portion of the deformation).
- Some of the deformation is not recovered. This deformation is called permanent set.

$$\sigma_0 = E(t, T)\epsilon(t, T)$$

σ_0 = applied stress (usually a constant over the course of the experiment)
 E = creep modulus
 ϵ = amount of deformation (strain due to creep)

- If a material is loaded for a long period of time, at a high temperature, with a substantial load, the sample will eventually break. This is called creep rupture

Handwritten notes: Polymer, 30°, 60°, 75°

So, the creep test is a load is applied over a period of time, causing the material deform. When the load is removed, a small amount of deformation will be immediately recovered because it is a viscoelastic nature; the elastic or a short-range portion of the deformation. Some of the deformations are not recoverable so, it gets into inelastic region. The deformation for a permanent set is called this; this is the applied stress, E is the creep modulus, which is a function of t and T; time and temperature and this is the amount of strain it undergoes this time and temperature.

If the material is loaded for a longer period of time at high temperatures; for example: I expose a polymer at 30 degrees. I expose a polymer at 60 degrees, same way I expose at 75 degrees; this time and temperature is a very important parameter to dictate the polymer behavior. So, this will substantial load with a substantial load the sample will eventually break and this is called as a creep rupture. So, creep strength depends on time, temperature.

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The slide features a title 'Dynamic Fatigue Test' with 'Dynamic' written above it. Handwritten notes in red ink include 'Compression' above 'Fatigue Test', 'Tensile' and 'Combination' to its right, and 'Time' and 'mg' further right. A list of three bullet points is present, with several terms underlined in red.

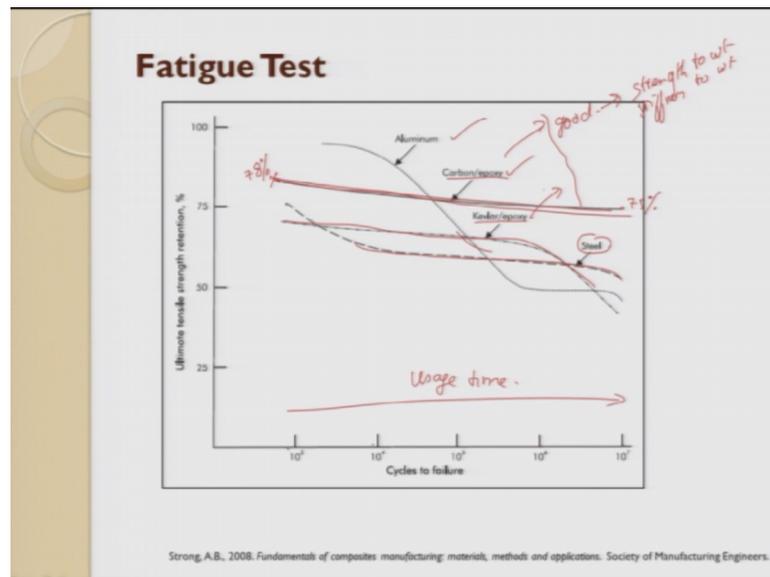
Dynamic
Fatigue Test

- Composites and almost all other materials are negatively affected by intermittent loads applied over long periods. This phenomenon is called fatigue.
- The fatigue test is performed by measuring a critical property in a composite, such as tensile strength, and then subjecting the sample to intermittent loads over long periods of time.
- The critical property is re-measured after set numbers of cycles.

So, next one is fatigue. Till now whatever we saw was static loading, now we will get into dynamic loading; fatigue. It can be compressive load, it can be tensile load, it can be a combination of this and when you do a combination it can change with respect to time and magnitude. You can try to do several variations of this and then try to understand how is your material responding. So, what are you doing, you are trying to do a dynamic study and then trying to understand how is your behavior of your composite.

The composite and almost all the materials have negatively affected by intermediate load applied for a longer period of time. This is called as a fatigue or it is otherwise a cyclic loading. The fatigue test is performed by measuring a critical property in the composite, such as, tensile strength and then subjected to the sample with an intermediate load over long period of time. That critical property is re-measured after a set number of cycles.

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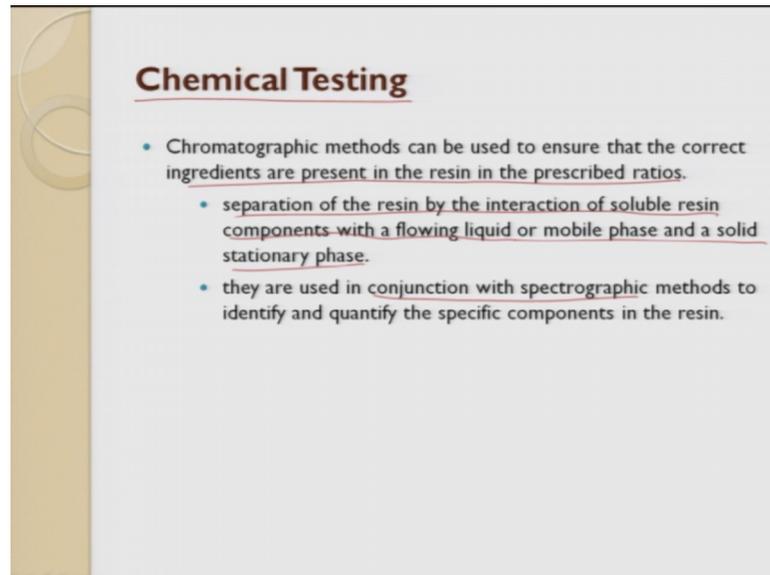


If you look at the graph, you can see here, this is for aluminum, you can see this is for carbon composite. So, carbon epoxy composite; you can see for Kevlar, it is also stationary for a long time. Look at steel, if you want to replace steel with Kevlar or with carbon it is good. Why, it has a strength to weight, stiffness to weight. So, it is lighter weight components. Lighter weight components are products can be manufactured by using carbon or Kevlar.

If you see that, if there is a gradual decrease in their expansion like for example; ultimate tensile strength retention, percentage if you see from here it is somewhere around about 78 it goes around to 75 percentage, when the number of cycles are gone up to 10 to the power 7. 10 to the power 7 cycles you have done and you see the decline in the tensile strength. This is the tensile strength or people call it as residual tensile strength you can see Kevlar; Kevlar also follows the same after 10 to the power 6 there is deterioration.

But, whereas you take aluminum, even 10 to the power 4 cycles there is a declination of this, but however in the start it gives a better performance, but when it is put for a longer use this is a usage time. We see composites outperforming the homogeneous material. Steel you also has a strong declination and think of steel density, aluminum density and these densities.

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Chemical Testing

- Chromatographic methods can be used to ensure that the correct ingredients are present in the resin in the prescribed ratios.
 - separation of the resin by the interaction of soluble resin components with a flowing liquid or mobile phase and a solid stationary phase.
 - they are used in conjunction with spectrographic methods to identify and quantify the specific components in the resin.

The other one is a chemical test. Chemical test is the chromatographic method can be used to ensure the correct ingredients are present in the resin as per the ratio. What are the ingredients; maybe you will add some hardener, you will add an infrared absorbing or infrared protection things and you might add some water or there might be presence of water. So, you would like to know from the chromatographic methods, what is the composition of it. For example; if you take metals you can do XRD, for this we try to do a compositional and then we also see what are the functional groups, how are they responding, what is that and other things.

Separation of resin by interaction of soluble resin components with a flowing liquid or a mobile phase of a solid stationary we can do. They are used in conjunction with spectrographic methods to identify and quantify the specific components in resin.

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Thermal Testing

- Metals and ceramics have a response to temperature that is uniform in all directions.
- The **coefficient of thermal expansion (CTE)** is independent of location within the metal and ceramic.
- The CTE for metals is usually constant over the entire range of temperatures for the solid metal.
- For composites, the CTE is different below and above Glass transition temperature (T_g)
- The rubbery state above T_g expands from two to four times, more than the glassy state below T_g , and the CTE in both states is substantially higher than the CTE for a metal or a ceramic.

The graph illustrates the relationship between thermal expansion and temperature. It shows a linear increase in thermal expansion with temperature, with a sharp change in slope at a point labeled T_g . Handwritten notes in red ink include "Tg - glass transition", "Solid - liquid", "liquid - gel", and "Temp?, TS ↓".

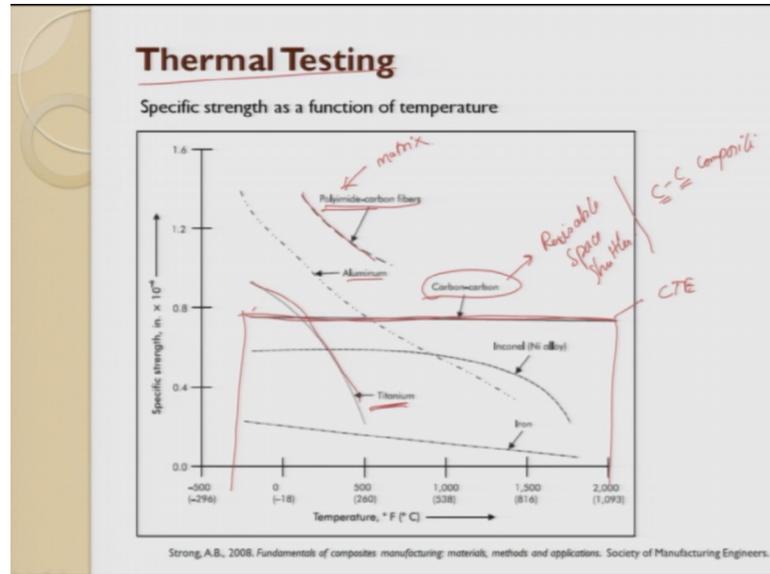
The next important thing is thermal cycle. So, we try to do, today we have several static devices as well as dynamic devices, to measure the thermal properties. Basically, the coefficient of thermal expansion properties we are trying to measure through this thermal test. The ceramics and metals have a good response, but polymer based on the choice of the polymer with respect to temperature, it declines. The coefficient of thermal expansion is independent of location within metals and ceramics.

The coefficient of thermal expansion is usually constant over the entire range for a solid, but whereas, when you take for a polymer, you can see there is thermal expansion happening and then you will have a 2 slope curve and when these 2 slope curve intersects it is called as glass transition temperature. This glass transition temperature will try to make a solid into a liquid or a liquid into a gel and it will try to me at this point you do the process or this is a point after which there is a decline in the or enhancement in the thermal expansion.

For composites, CTE is different below and above the T_g . T_g is a very important point. T_g is otherwise called as glass transition temperature glass. So, this point is very important we have to find out for all polymer material. The rubbery state of T_g expands between two to four times, more than the glassy state below and T_g you see. If your service condition goes higher than this you are going to see a failure.

So, what happens when this thermal expansion more; when the temperature goes high, the tensile strength goes low. So, this is a very disastrous thing.

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If you see the thermal testing, you can see for titanium, you can see for aluminum with respect to temperature you can see for inconel, it is all like it can go up to 1000 degrees, but whereas, when you take a polyimide-carbon fiber, you can see, and then for a carbon-carbon fiber you can see, how is the response. So, carbon-carbon has a steady response that is why it is used in reusable space shuttles, because of it is thermal testing thermal because of is CTE Coefficient of Thermal Expansion. The specific strength does not decline from minus 2 plus. So, this is why we more talk about c-c composites today.

So, c is c is the carbon fiber c is the matrix. We take a polymer, we graphitize it and make it into carbon and that is how we make. All the reusable space shuttles which goes from minus to plus when it reenters huge friction, these are the materials used. We can see for iron what happens, you can see for polyimide what happens, this is predominantly because of the matrix polymer.

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Rheological Testing → *Visco elastic material.*

- Rheology is the study of deformation and flow.
- It is frequently used to determine the flow. (*viscosity changes*) of uncured resins.
- The viscosity of an uncured resin is usually determined by a parallel plate rheometer.

Two competing forces:

- (1) As the temperature increases, the mobility of the molecules increases and the viscosity falls; and
- (2) As the temperature increases, the molecules start to react and grow in size, leading to an increase in viscosity.

trade off

Parallel Plates

liquid

The slide contains a diagram of a parallel plate rheometer. It shows two horizontal parallel plates with a liquid layer between them. A vertical arrow on the right indicates the direction of shear. The text 'Parallel Plates' is written next to the diagram, and 'liquid' is written below it. The word 'trade off' is written in red on the left side of the slide.

Next and the last is the rheology; why rheology, because the polymer is a visco elastic material, so that means to say, the behavior changes with respect to time, temperature. Rheology study; rheology is the study of deformation and flow; deformation means shear deformation and flow. It is frequently used for determining the flow, viscous change in the uncured resin. There is an uncured and there is a cured resin, when the uncured resin is used, we try to find out the visco elastic behavior and then start adding ingredients to get it.

Viscosity of a uncured resin is determined is determined by; so what we do is, we try to take two parallel plates and then try to put a droplet of or whatever is the this thing. So, this is a plate, these two are parallel plates and then we put liquid here and then what we do is we try to swing the plates and then try to see, what is the resistance it generates and how is it doing with respect to time and temperature. So, this is what is called as a parallel plate rheometer.

Two competing forces are; as the temperature increases, the mobility of the molecule increases, viscosity falls down. As the temperature increases the molecules starts to react and grow in size, leading to an increase in viscosity. So, there has to be a tradeoff between these two. For this, we always try to do a rheology parameter. Rheology can be done static, it can be done dynamic. Static what we do is, it does not give a proper

response, we always use a dynamic rheology testing device to measure the mobility of the chain. The mobility of the chain cannot be measured, the viscosity can be measured.

So, with this I come to an end of lecture 5 and here I wanted to put an assignment, but I thought in this to do any testing or to have any understanding. We need to have an instrument, if anybody has an access to an instrument. Please, try to test any one composite product or a part which is available with you and see the response.

Thank you very much.