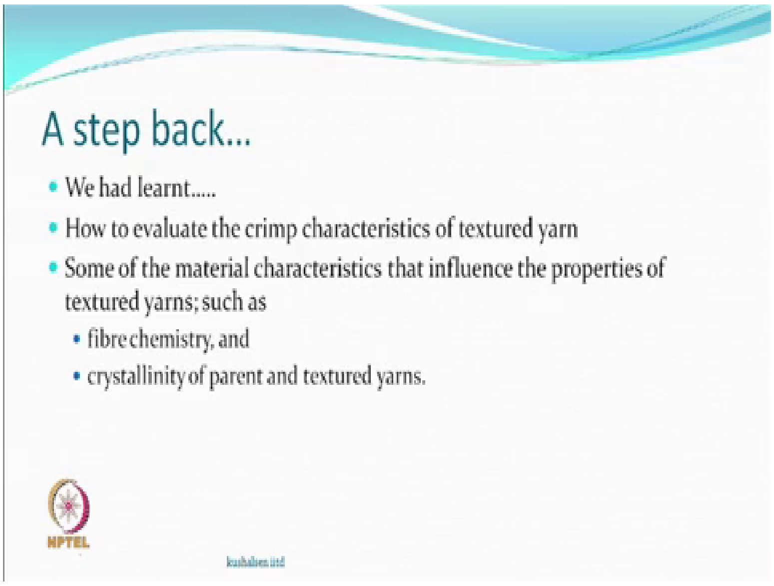
Textured Yarn Technology

Prof. Kushal Sen
Department of Textile Technology
Indian Institute of Technology, Delhi

Lecture - 08
Influence of material and process parameters

So we get to the lecture 8, which is on Influence of Material and Process Parameters. We hope that, we will be able to complete this otherwise we will continue further.

(Refer Slide Time: 00:35)

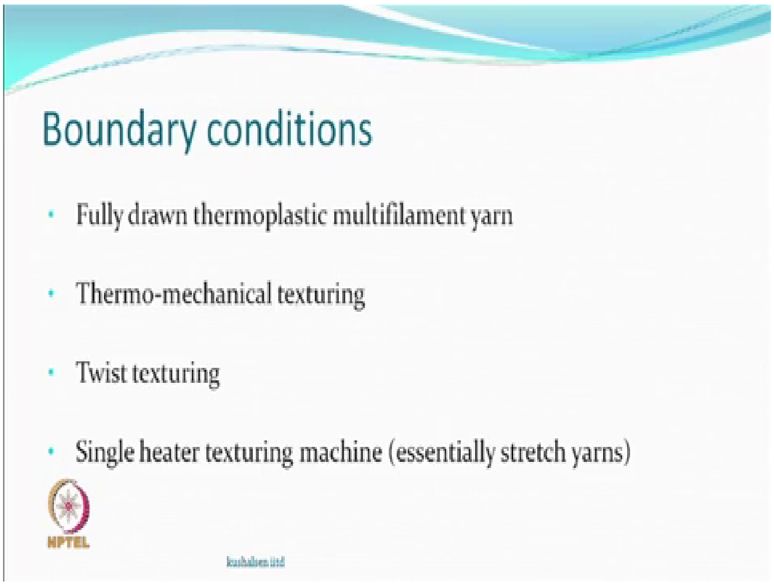


A step back...

- We had learnt.....
- How to evaluate the crimp characteristics of textured yarn
- Some of the material characteristics that influence the properties of textured yarns; such as
  - fibre chemistry, and
  - crystallinity of parent and textured yarns.

So, a step back means we learnt, how to evaluate the crimp characteristics of textured yarn. And we did talk about some of the material characteristic that influence the properties of textured yarn, such as the fibre chemistry and crystallinity of the parent and textured yarns. So, we continue with this material parameters and see what kind of influence that can have.

(Refer Slide Time: 01:05)

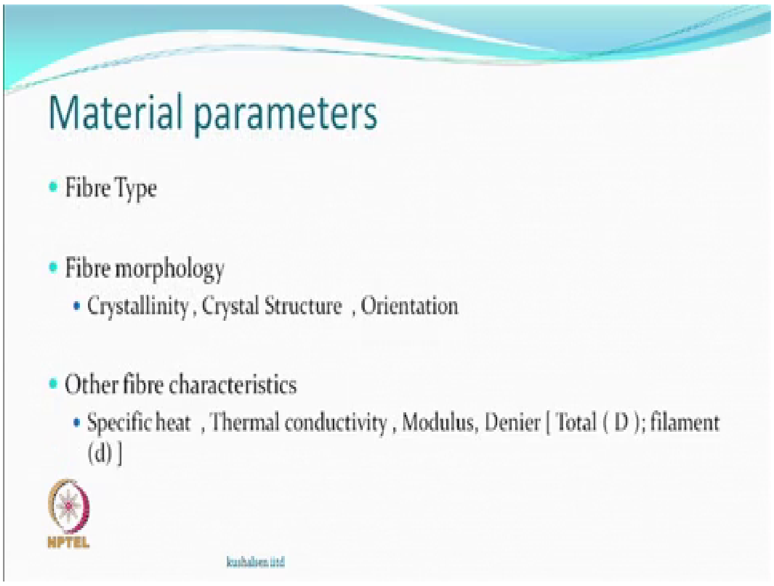


Boundary conditions

- Fully drawn thermoplastic multifilament yarn
- Thermo-mechanical texturing
- Twist texturing
- Single heater texturing machine (essentially stretch yarns)

So the boundary condition still remain the same, we have working on thermoplastic multifilament yarns; we looking at twist texturing thermo mechanical texturing and a single heater machine.

(Refer Slide Time: 01:19)

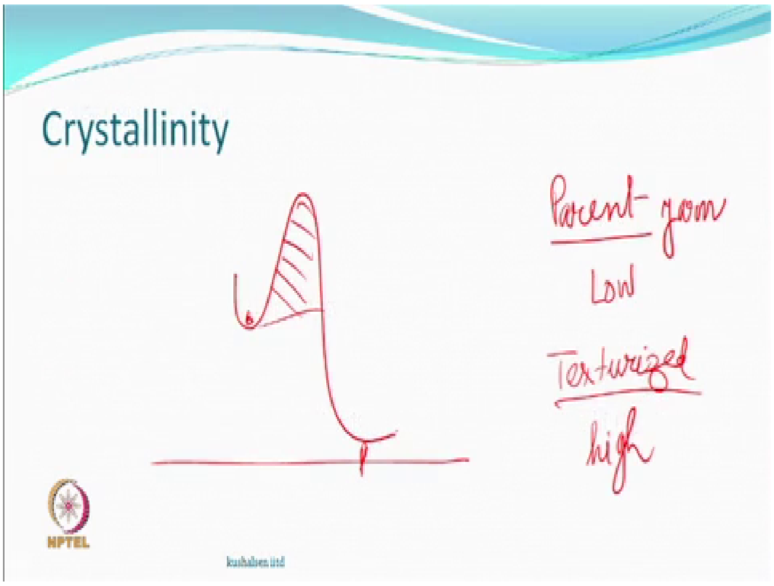


Material parameters

- Fibre Type
- Fibre morphology
  - Crystallinity , Crystal Structure , Orientation
- Other fibre characteristics
  - Specific heat , Thermal conductivity , Modulus, Denier [Total (D); filament (d)]

Last time if you remember, we said the material parameters would be of the type fibre, fibre morphology which mean crystallinity crystal structure orientation and other characteristics like specific heat, thermal conductivity, modulus denier and filament. So, hopefully we should be able to complete at least this.

(Refer Slide Time: 01:39)



Crystallinity

Parent yarn

Low

Texturized

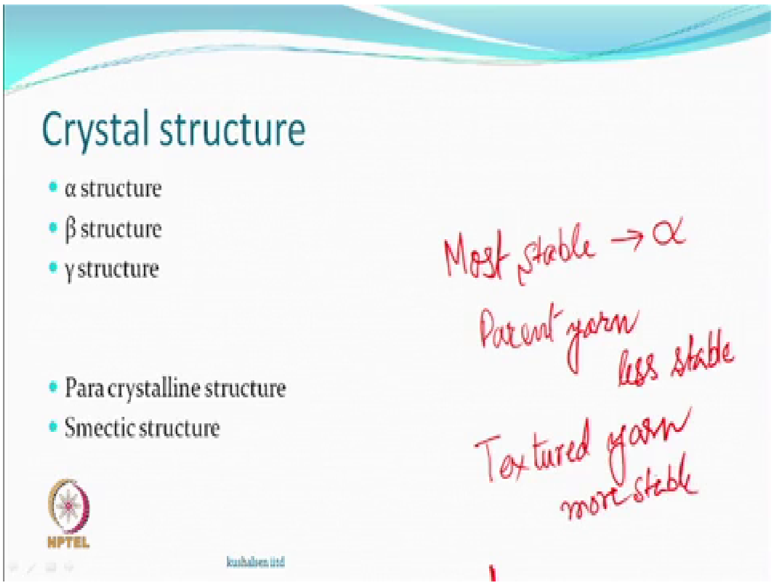
high

kushalsen.iitd

So, we remember that the parent yarn crystallinity should be as low as possible. And after texturing, if the crystallinity of the textured yarn is high, then it will be good for us.

We come to crystal structure.

(Refer Slide Time: 01:59)



Crystal structure

- α structure
- β structure
- γ structure

- Para crystalline structure
- Smectic structure

Most stable → α

Parent yarn less stable

Textured yarn more stable

kushalsen.iitd

So, one is crystalline portion and amorphous portion, we understand crystalline portion is more rigid difficult to change; you have to give more energy before it changes. But the crystal that form can actually have different structure you can have triclinic, monoclinic and so on so forth so, you can have a different structure. So, some of the polymers like polyester have only one type of structure; crystalline structure every time from amorphous to crystalline it goes it takes only one kind of structure. And some other fibres like nylon; generally depending upon how you are spinning can have 2 types of structure called the alpha and beta.

And polypropylene which we said is also a good material for texturizing can actually have, alpha, beta, gamma type of crystal structures. Some materials like acrylic do not really show very highly defined without flow, without any defect crystals. And therefore, in general their crystalline structures are somewhere in between not amorphous and not fully crystalline, but somewhere we call as a para crystalline structure. And polypropylenes also have another structure which is in between somewhere called the smectic that you can have, some order. But the whole region is not totally crystalline and so that the smectic type of a structure.

This term which is alpha, beta and gamma have nothing to do with the angle of crystal. You know you have the angle, it is basically more to do with the stability of a structure. So, you can have more stable structure so; obviously the stability, if you define in terms of the amount of energy internal energy. Then all the structures will have different energy. So, their different stability, one will be more stable than the other and so, as a nomenclature, whatever is the most stable; is called the alpha structure.

So, whenever somebody say that we have alpha; that means, more stable within the same polymer alright. And how do you get? For example, if you draw of fibre; you may get a mixture. In case the polymer has mixture of, the crystal structures. When you heat set, anneal it. Then there is a change, there is a transition and it will have the tendency to go to the more stable structure. And that would be called alpha structure alright.

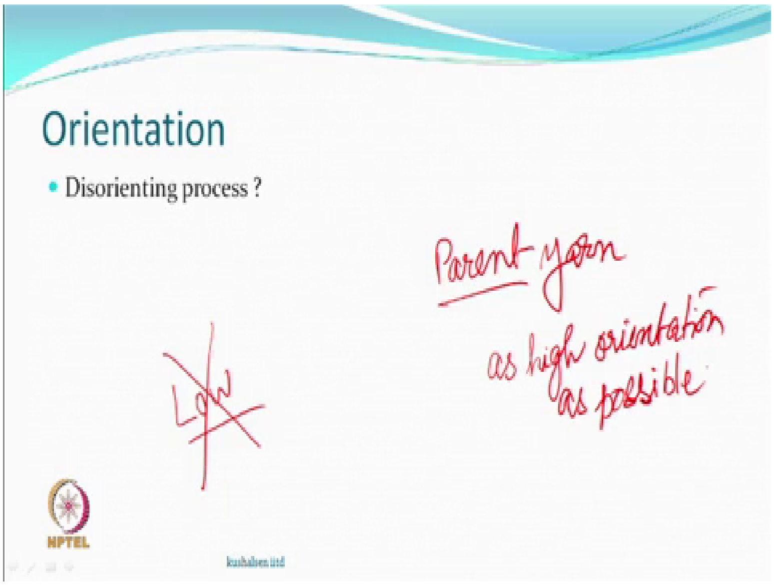
So, all this can be found, if you go to the lecture and see what type of crystal structure? Let us say the different polymers show, ok. And you also appreciate; that the crystalline structure formation has something to do with the chain folding. One is stress induced where the chains can come together, but when you anneal and give freedom. The chains can fold over each other.

And so wherever there is a possibility of easy folding versus difficult folding so, you will have different kind of structure. For example, you may be aware that there is something called normal spinning of a melt spun yarn or high speed spinning. So, when you do high speed spinning the time available, for getting down to the nice beautiful structure would be less, because the it gets cool down to a solid state once it becomes solid then; obviously, change is become more difficult. So sometime whatever best could have been done is done.

So, you can find various structure? So, now, let us say if the question with us is the texturing. So, when we have a parent yarn, would it be advisable? If you have a choice that you have parent yarn should have stable structure, which is the alpha or should have other than alpha structures which you may like to have for the parent yarn right so, you want less stable structure.

So, as far as the parent yarn is concerned. You want less stable. Why do you want less stable? Because we said this whole process texturising is partial melting and re crystallization. So, if you have a less stable structure it will be easy to melt partially so, that molecular change become free and they can go back to another structure, which may be more stable and so, it is; obviously, easy to conclude that in the case, in the case of textured yarn obviously, finally, you will want stable structure. That is more stable structure. That means, if we have another parameter, if you have a choice? You can think about it and utilize. And people do get smart if they know more about it.

(Refer Slide Time: 08:45)



Orientation

- Disorienting process ?

~~Low~~

Parent yarn

as high orientation as possible

Then orientation, in a fibre or a filament is defined. That if the various segments phases like crystalline phase, amorphous phase or the molecules. If they have they are more oriented towards the fibre axis along the fibre axis then you say it is more oriented structure ok. So, if you draw the orientation improves, if you heat set the orientation can go down because, you are given the freedom and freedom means with you can take any position which the molecule or the; the segment or the phase likes ok.

You know how to measure orientation in a fibre, how do you measure orientation?

Student: (Refer Time: 09:43).

Yes, the birefringence is one method by which you can get an overall orientation. If somebody wants to say, well I want to know, what is the level of orientation of the crystalline phase and what is the level of the amorphous phase? Can you define, can you do that also? Segregate them how do you do that?

Student: (Refer Time: 10:07).

How did the anyone else?

Student: X ray diffraction

X- Ray diffraction. So, from the X ray diffraction you can possibly get, the orientation of the crystalline phase and then you can have relationship from the birefringence you can go and segregate amorphous and the crystalline part. So, you can find an orientation, of a fibre. So, you can have the same thing orientation of a parent yarn. If somebody says well you have a choice would you want the orientation of the parent yarn to be high or low? So, what do you say?

Student: Low.

Low, ok.

I just note down, you are saying low. So, how many people believe that should be low? 1. So, others all do not believe it? You can appreciate; when you draw a fibre, you improve the orientation. In what way it will help? If you have higher orientation, what are the general property which are likely to be affected?

Student: (Refer Time: 11:36).

So, tenacity may be higher, modulus could be higher these are the properties you can think these will be higher. Why this happen is, because the stress the level of the direction of the stress, is along the direction of the fibre axis or a yarn axis; so, all the entities try to orient themselves towards the direction of the force right the tension that you have. In the case of texturing what you are doing is, you are taken a fibre, and if there is any stress in the yarn which should be. The stress is in the direction of the yarn, while it is being heated, but the filaments are twisted; the filaments are not a parallel bundle while they are being heated.

And therefore, if you look at an individual filament, the direction of stress maybe oblique to the direction of the fibre axis; why the filament is being helical, the yarn has a direction. So, when you say this is the yarn, but the filament is like this and the stress is in this direction. So, a filament which is just moving over, it experience a stress and the direction which is not in the direction of the filament axis.

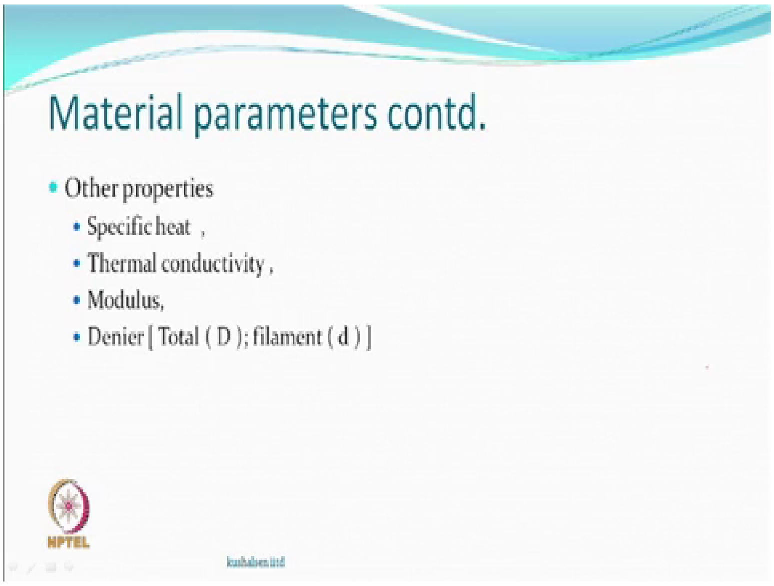
So, now, the stress is in different direction and what is the role of a stress? To orient all the entities towards the direction of the stress. So, when you get back and get a textured yarn, the textured yarn is going to be tested when there is no twist. Remember, a textured yarn is a parallel bundle, of twist lively filaments which have no overall twist.

So, when you are testing it will be after point one gram per denier it will be a parallel bundle. And now you will be testing the orientation let us say. So, what value you will get? Will be reduced. Even if there is a stress in the yarn, because the filaments are in a helical position. So, if we can make a statement; that texturing is a disorientating process. Whenever you texturize, whatever you do the orientation; in the filament, is going to reduce it will not increase. Unlike the case; when we said the crystallinity can improve. Because you are going to a more stable state, crystalline structure can go to an alpha state, usually more stable state.

But after texturing, the orientation of the filaments is going to go down. So, you can say it is a disorientating process. It is going everything is going to disorient. So, when something disorients. So, you are quite sure, as you said the tenacity, as also the modulus; of the yarn, is going to be low; will reduce. So, the common sense therefore, says is well whatever it is, crystallinity we have already handled. If suppose we have independence; crystallinity is constant, orientation is high or low. So, we may say well, we may not go for a low orientation; we may like to have a parent yarn, with as high orientation is possible. Is again a choice?

So, slightly different, way to look at it. Because you will still want although we said, tenacity at brake of a textured yarn may not be very important. But why do you want to, reduce it further if it is possible for you to have better. Because not going to give you too much of advantage its only disorientation process.

(Refer Slide Time: 16:25)



Material parameters contd.

- Other properties
  - Specific heat ,
  - Thermal conductivity ,
  - Modulus,
  - Denier [Total (D); filament (d)]

So, we look at; some other properties also, which means, specific heat, thermal conductivity, modulus etcetera. So, these are also the properties. They would play some role, in heat transfer, heat storage and of course, flexibility etcetera. So, specific heat is one, it is specific to the material. You take polyester, you take nylon, you take polypropylene, if you have it been given a choice you know. If you have no choice, then you have to have a choice, but if you have a choice what would you want? Specific heat, of a parent yarn to be low or high.

(Refer Slide Time: 17:15)

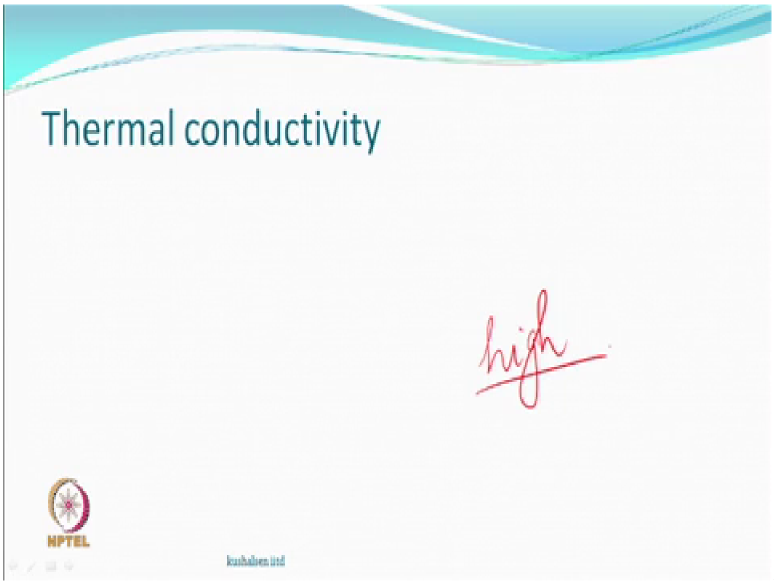
Specific heat

Low

kushalsen iitd

So, there is no confusion here. Because that would means you will require less amount of energy to, raise it to a certain temperature which is the optimum temperature. Because a temperature has to be optimum, you have to go to that temperature, everything is a room temperature. So; obviously, you like to spend less amount of energy, to go to the same temperature. So, there is no confusion here.

(Refer Slide Time: 17:43)



Thermal conductivity

high

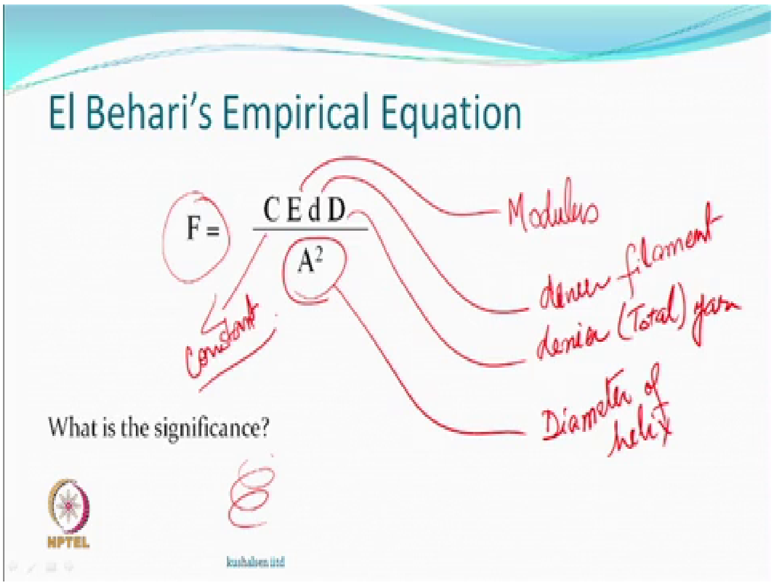
kushalsen iitd

Thermal conductivity, the thermal conductivity is a heat transfer. Because the heat is being transferred, either through the air, may be by convection systems or through a contact heater, which is a metallic system. From that to the fibre, the yarn has the, the heat has to be transferred. So, it is obviously interesting, if the thermal conductivity is high. You will get surprised, that the conductivity of different fibre is different like polypropylene has a poor thermal conductivity, polyester also has. Now how does matter to us? We will may be we will have to think about, when you are giving some time. Because we cannot change temperature, optimum temperature cannot be changed very easily.

Time, may be you can think about it; or the length of a heater, and thermal conductivity also is important not just during heating, but also during cooling. So, in one case you have heater, which is a higher temperatured higher temperature and a heat is being transferred to the fibre. Once the filament exits, the heater it must get, it must get cool down before the twister, to a temperature which is below, the glass transition temperature, otherwise whatever you have done can be undone. So, this property could be important, and if you cannot; obviously handle you say, by somebody has to texturize polypropylenes. So, you have to texturize polypropylene you cannot do much about it.

Then you have to think about the time, they have to think about, the lengths of the heater, the length of the cooling; area. So, all that will have to be, worked around, based on what kind of a material saw. So, finally, if we say; that we want, low crystallinity, less stable crystal structure, high orientation, low specific heat, and high thermal conductivity, alright. This is how we work.

(Refer Slide Time: 20:11)



El Behari's Empirical Equation

$$F = \frac{CEdD}{A^2}$$

Constant

Modulus

denier filament

denier (Total) yarn

Diameter of helix

What is the significance?

So, there are three other things, which are related to some of the properties, dimensional or mechanical properties, of the yarn.

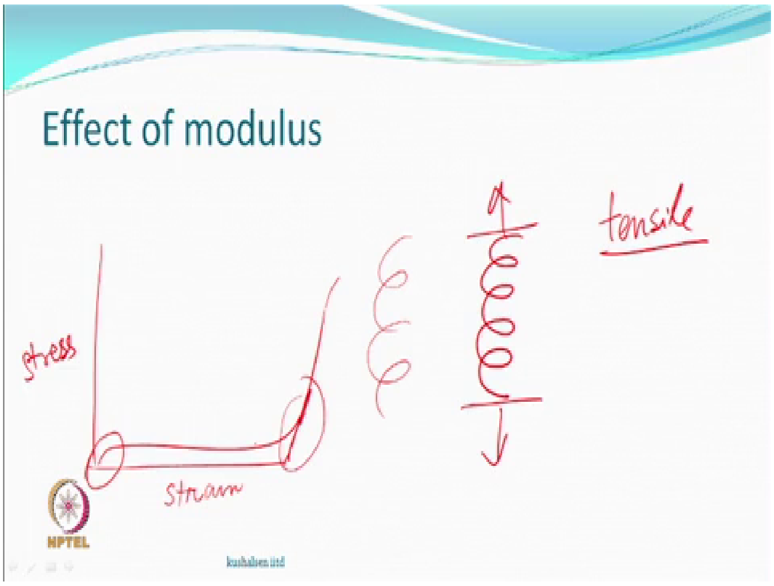
This is a force, a resistance that will be offered. Let us say you have made a helix. So, is a force, when you stretch, or after stretching it ones you recover. So, whenever you stretch you will experience a force right the resistence. So, that kind of a thing. So, you made a textured yarn, and obviously, you are stretching. So, there is resistance being offered, and empirically, they have found the group, l Bihari and Atal. They found, that it is related to; the modulus, the denier which is, filament denier, individual filament denier. And denier, total of the yarn ok. And this, is diameter; of helix. So, there is something called, a formula derived from fundamentals, ok and you get to an equation the other way is experimentation.

So, when you say empirical equation, that mean people have done experiments. And then they, after large number of experiments they find what this is, how the things behave; and this is how we would like to understand.

Student: what is c here?

Alright, that is a good one. So, this is some constant, ok. This constant will change, based on the units that you take, in meters, centimeters, inches, foots, pound whatever. So, this constant will change.

(Refer Slide Time: 23:11)



Effect of modulus

Now, the question that remains is, why the modulus of the yarn, whichever you are using would have anything to do with. Let us say, the this force, the resistance, to deformation. So, what do you have? So, you may be having, a thin helical system with a thick. I am surprised that actually is been; it looks like this may not ok. If you have a, what we are looking at? Is the modulus; of a material which is, of any type, and what you want to do, is extend stretch.

So, which modulus are we talking about first. Can you just guess? Obviously, it is a textured yarn. Without textured yarn, there is no question of it, a textured yarn also, which type of a modulus we are talking about. We have, right. So, this is your; textured yarn. So, which modulus are we talking about? Important thing, which you must remember is, that this test, when it is performed; obviously, it is like a tensile test. You can have something, can try and measure here or you can measure here, where which one we would like to measure at? Right.

So, it will be, interesting that the stresses that build up here; are the one which are the property of the basic material. This is only crimp or helix opening, this area in the beginning is the opening of the helix right, this is opening of the helix. And so, that is in some way, related to what sometimes we call as a low strain property.

(Refer Slide Time: 25:55)

Low strain property...

$F \propto E$

Low deformation

Crimp Regidity

So, crimp opening and going back to crimp. So, what you are saying there is a crimp, which was there, maybe helical structure, and after putting a stress it open. Then when you, leave it, it goes back, to the crimp state. Does the filament in during this process actually get extended, in length? The helical structure, you put some load, the crimp is gone, and then it is come back.

Whether the length, of this filament changes; during this process?

Student: (Refer Time: 26:53).

No.

Student: (Refer Time: 26:57).

No. So, this opening of frame and coming back to the crimped state. There is some deformation, because it was in this state, and now it is a flat state. So, there is a deformation, but this is; low strain, low deformation, low strain and low defamation condition. Which for tensile property of any material is related to low deformation?

Student: Tenacity (Refer Time: 27:46).

Tenacity, extension brake, modulus, which property is related to low deformation?

Student: (Refer Time: 28:01).

It is modulus. Because, you are looking at a very very low deformation, and want to say what kind of stresses build up alright. So, this stretching and recovery, which is what determines, or which is what will finally, get to you a value called the crimp rigidity. If this force of the resistive force is high, then it will recover well also, unless some break occurs you know. We are hoping that, damage is not occurring during this process. And so, this force is in some where related to crimp rigidity.

So, if someone has said; that it is actually related to, this F is proportional to E was wrong or right?

Student: (Refer Time: 29:17).

So, it is reasonable because this whole thing is related to, the modulus. Because modulus is a low strain low deformation property. So, if you try to relate this force with, tenacity at brake. You will find almost no relationship, but here it was true alright. So, that means; if you have two types of fibres, almost handled in an optimum way, one of them actually has a high modulus, and other has a low modulus.

So, you can expect, similar results in the crimp rigidity. For example, between nylon 6, and nylon 66 ok. Because of the molecular structure, let us say the best possible state that you have a crystalline state, which is alpha state. In that case what you have? There is something called a anti parallel structure, you have a molecule, one molecule, let us say in this way.

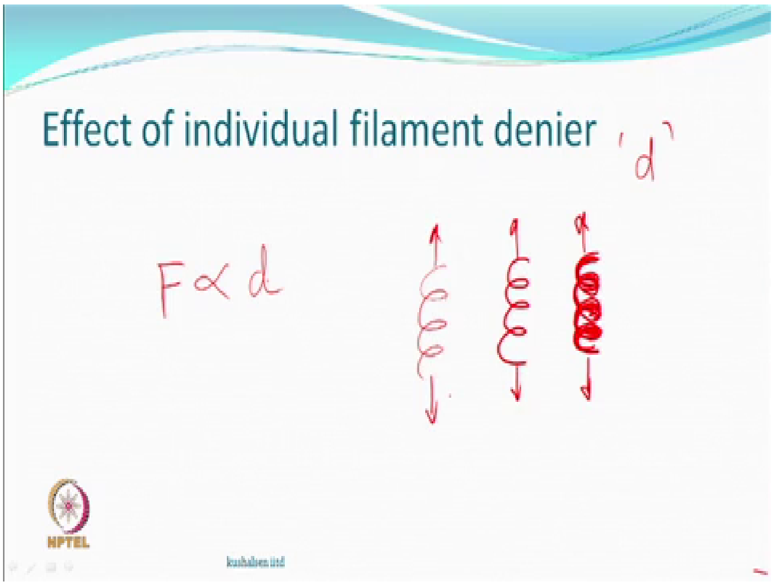
Student: (Refer Time: 30:58).

Like you have CH 2 CH 2 NACO and the other hopefully this way. And if you are lucky let us say, this is CO and this NH, and then may be CO somewhere etcetera. If they come very close, then they make hydrogen bonds.

So, intermolecular hydrogen bonds, if the possibility of forming intermolecular hydrogen bond is high. Because of the molecular structure itself, then the modulus of that particular fiber could be high. So, generally if seen nylon 66 gives, higher modulus compared to nylon 6. Polyester also gives higher modulus, because of the aromatic ring it have, it gives rigidity extra rigidity; polypropylene may have low modulus. Although you must remember, this modulus is something which you can manipulate also, if you do more drawing, the modulus can change. But then if you do more drawing the denier changes, then you have a different you know parameter come into play, but nevertheless.

So, you can try to do one exercise, at home; to draw anti parallel structure, of nylon 6and nylon 66. And check, by this kind of geometrically representation representing these molecules, can you somehow prove that one of them would probably make more intermolecular hydrogen bond than the other? This exercise you may like to do you can.

(Refer Slide Time: 33:07)



Effect of individual filament denier 'd'

$F \propto d$

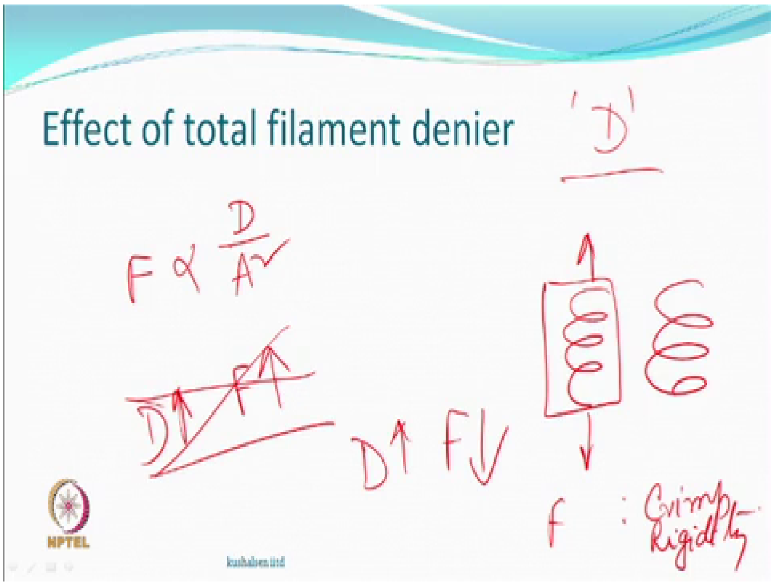
So, individual fiber denier or filament denier, which is represented there is a small d, how is it is it related to the F, how is it related to F? It appears this is related to, denier directly proportional. Why? Here I am just trying to draw, maybe a thicker helical, thing you want to stretch this, what is this, what is this, which will be easier to stretch, or which will offer more resistance? The one with.

Student: Greater diameter.

Right. So, this also appears that we have we whatever we have stated is correct because you can appreciate when we are opening, or it is a small deformation. But what you are doing is, something which was inside the curve, versus which is outside the curve. So, when you deform them, the larger is the distance between these two surfaces, The more is the force that is required to unbend the crimp. And if nothing changes, then it will also like to go back easily. If it is very fine, then the resistance offered is less. Because at least bending is happening, or unbending is happening. So, and bending unbending situation, if the distance between the two surfaces is high; that means, the diameter is high, denier high means, the diameter also must be high.

And so, this is what the reason, why you find is that this particular factor also is proportional to the force resistance.

(Refer Slide Time: 35:59)



Effect of total filament denier

So, total denier would mean that we are looking at changing the things maybe by number of filaments; instead of 20 you have 40, keeping the small d constant and you can still increase the denier. So, in this case what is expected? If I increase the total denier of the yarn what do we expect? The force resistance to go high, right. So, you expect it should also be, that if you increase the total denier, the force will also increase, this is what we mean right.

So, they did experiments. Because you say this is an experimental formula empirical. And what they found was, when you increase the D, F goes down. So, this is it did not happen. It was interesting for them also. So, the D can be increased, by increasing the number of elements or it could be increased by increasing the individual denier per filament anyway. But whenever they increase the total denier, they found the, stretch potential. If we can call that also, goes down. What do you think, could have been the reason?

Student: Cross sectional area.

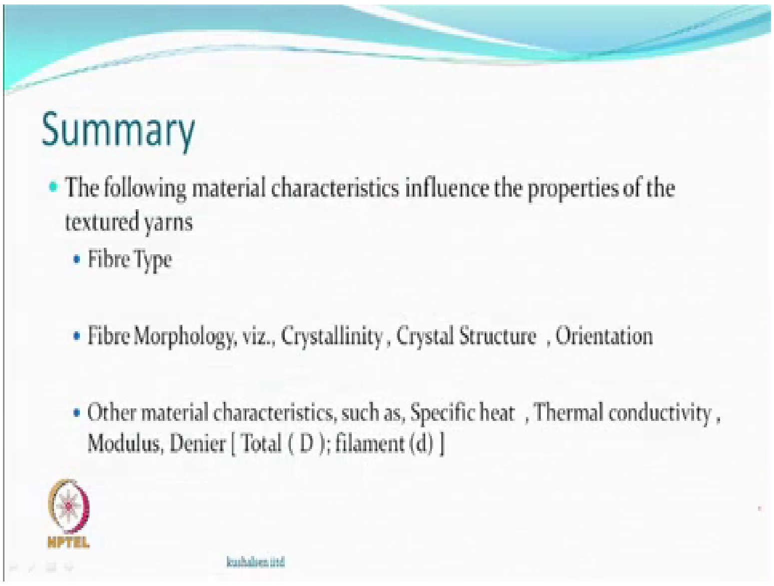
Cross sectional area, let us say is all circular fibres to begin with right. So, you are looking at diameter of a fibre filament right. But they found one interesting thing, that whenever the denier is high, the diameter of the helix is also high. So, if you have a two situations, where the diameter is this; of the helix verses this. In your own opinion, which one will be offering more resistance if the individual denier of the filament is the same. The one with a larger helix or smaller helix?

Student: Smaller helix.

The smaller helix therefore, is going to offer more resistance. So the, what they found that; when you change the capital D that is the total denier, you cannot independently change this, independent of the filament the helix diameter. So, that also increases, and they found that is proportional, inversely proportional to the square of the helix diameter. So, it actually becomes very easy as you keep increasing the diameter. And so, F is not proportional to D, but was found to be proportional to D over A square. And therefore, if you only look at D then you get the inverse relationship. And that is how this particular, understanding came, from the point of view of the texture.

So, one more thing obviously, you can always remember is this F as I said has something to do with crimp rigidity. Because you will, it is easier for you to do texturization and after that you measure the crimp rigidity, and then correlate it, with whatever you did. You change the individual filament denier, you change modulus of the material or you change the total denier, whatever you want, all that you can look into it. So, we summarize here.

(Refer Slide Time: 40:49)



Summary

- The following material characteristics influence the properties of the textured yarns
  - Fibre Type
  - Fibre Morphology, viz., Crystallinity , Crystal Structure , Orientation
  - Other material characteristics, such as, Specific heat , Thermal conductivity , Modulus, Denier [Total (D); filament (d)]

There is the chemistry of the fibre also the morphology, with its crystalline crystal structure orientation. And other properties of the material, which are related to the heat transfer, heat capacity, the modulus, the denier, and the total denier of the yarn, textured yarn and this is how, all this material characteristics. So, next time hopefully we will look at the process parameters and their relationship.