Theory of Yarn Structure
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Lecture – 03
Basic Characteristics of Yarns

Welcome to you all to these MOOCS online video course; theory of yarn structure, we have completed module 1; today we are going to start module 2. Module 2 speaks about basic characteristics of yarns like module 1; in this module also we are going to established a few basic characteristics of yarn. Let us start this module with this image.

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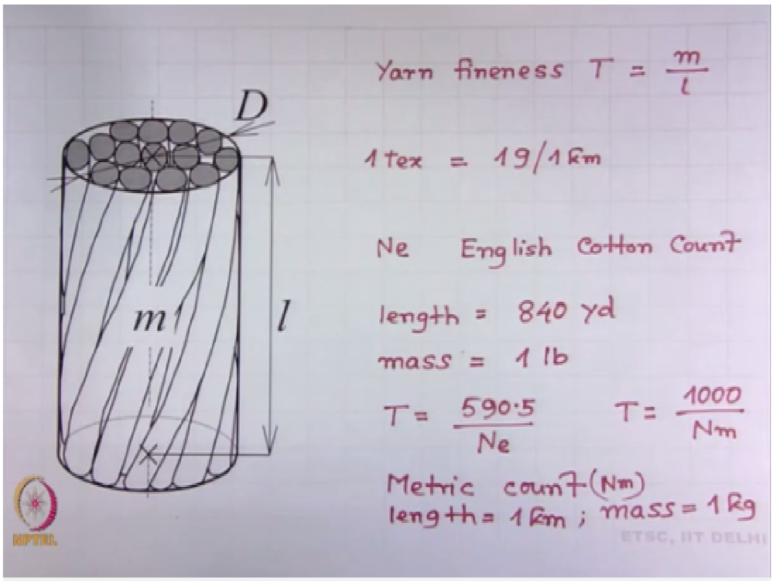

What you see is a staple fiber yarn or precisely a portion of a staple fiber yarn as you know, a staple fiber yarn is a twisted fibrous assembly where the fibers are inclined at different angles from the axis of the yarn, so in this image also you see a small portion of yarn, the length of this portion is l and the mass of all fibers is small m and you see another symbol capital D that denotes diameter of yarn.

So, let me repeat, this is a scheme of small portion of a yarn, l denotes the length of that portion of a yarn which is equal to fiber length, m denotes the mass of all fibers in this portion of the yarn and capital D denotes diameter of yarn. So, the first characteristic what we are going to speak on is yarn fineness, we use a symbol T to denote yarn fineness. So, as you know yarn fineness is yarn mass per unit length of yarn.

So, here m denotes the mass of all fibers that means mass of yarn and l denotes length of this portion of the yarn which is incidentally is also equal to fiber length, so we have selected the portion accordingly so, m/l. Now, there are different units to express yarn fineness, the one of the very common unit is Tex, what is 1 Tex; when the mass of yarn is 1 gram and length of yarn is 1 kilometer, we obtain 1 Tex.

And similarly, there are different units available to express yarn fineness, another common unit which is available to denote yarn fineness or yarn count is Ne, so is called English cotton count when now, what is Ne? In Ne, length = 840 yard and mass = 1 English pound, so if we would like to convert English count to Tex then, we use this expression, this all you perhaps known. There is another count; unit of count available which is called metric count.

What is metric count? In metric count, length is 1 kilometer and mass is 1 kilogram so, if you wish to convert this metric count to Tex, you use this conversion as you know Tex falls under direct system of counting and English cotton count and metric count fall under indirect system of counting, there are many more expressions units available to denote count, right. Let us now go for the second expression which is little unknown.

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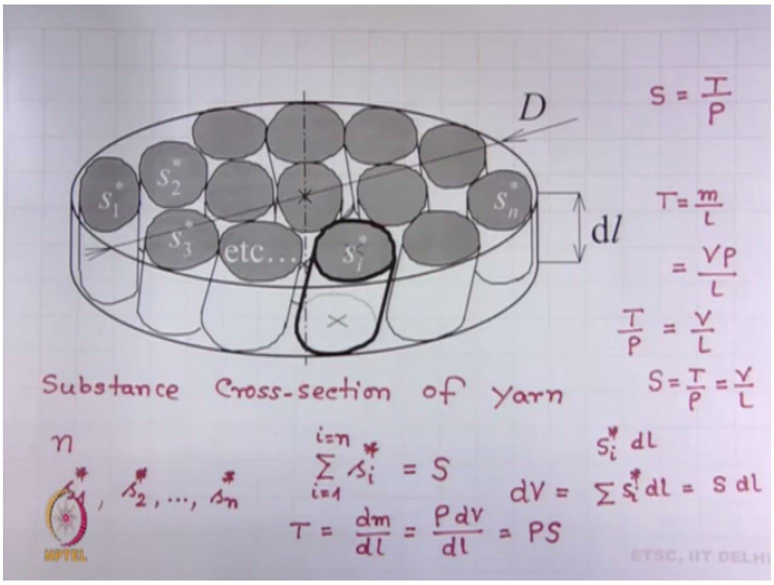

So that expression is related to substance cross section of yarn, is a very interesting and important expression which we do not usually follow in practice however, for theoretical understanding this expression is extremely important. What is substance cross section of yarn? Yarn consists of fibers and the fibers are twisted, so they are not straight, they are not parallel to the axis of the yarn rather they are inclined to certain angles from the axis of the yarn.

So, if we cut a cross section 90 degree, at an angle 90 degree from the yarn axis, cross section of a yarn then, if we put that cross section under light microscope probably we see an image like this what is shown here, what you see in this image; there are certain fibers let us assume n number of fibers, each fiber has a sectional area remember, it is not cross sectional area of fiber as the fibers were inclined, we cut a cross section.

So, these areas what you see are not cross sectional area, they are sectional area, it creates a huge difference you will see subsequently. Now, we denote we use a symbol star as a superscript to denote the sectional area, s superscript start subscript 1 that means sectional area of first fiber similarly; there will be second fiber whose sectional area will be denoted by this expression.

Similarly, there will be many n number whose sectional area will be denoted by this symbol, so in general, what we see is that there will be many section area let us denote a generalized sectional area by this symbol, right, okay. So, if we sum all these external areas then we get a quantity, we will denote capital S to express that quantity, so what is capital S? Capital S is the summation of all sectional areas of the fibers in the yarn cross section okay, right.

Now, what is the volume occupied by one single fiber, so the length of this infinitely small section is dl and capital D is yarn diameter, so the volume occupied by general ith fiber section is; * dl, so what is the volume occupied by all fibers in these infinitely small cross section of yarn; dV which will be very small summation dl, this dl is constant, so we can write S * dl now, what is the fineness of this yarn?

Yarn fineness we assume to be same in all cross section, so yarn fineness is mass per unit length. What is mass? Mass is density dl, so we obtained this expression, so what we obtained is S = T / rho, so if we know fineness of yarn, it is very easily determined in a standard textile laboratory, fiber density is also possible to determine experimentally, we will be able to find out substance cross sectional area capital S, right.

Now, what is the use of the substance cross sectional area? We need to understand this, to answer this question we have to little go back to the definition of yarn fineness, you remember we define yarn fineness by this T = mass per unit length right, now what is mass of yarn;

volume occupied by fibers say, capital V * density / L, so this T / rho = V/L now, this expression gives a very important message to all of us. What is that message? We generally perceive that yarn fineness talks about size of a yarn.

How much fine is the yarn, how much course is the yarn imaginatively, we think yarn fineness talks about the size of the yarn but this is not correct, why it is not correct because of this expression, if you look at this expression very carefully then, you will see that volume/length, this is an expression which generally denotes the size of an object which is != T rather which is = T / rho that means, it is possible that a yarn of same fineness; a yarn of a given fineness T prepared from lighter fibers say, polypropylene whose density is relatively low.

So, a yarn of a given count prepared from lighter fibers may be larger than a yarn of same count prepared from heavier fibers say, viscose whose density is higher than the density of polypropylene. I repeat if V / L denotes the size of yarn then it might be possible that a yarn of a given count T prepared from lighter fibers say, polypropylene may be larger than a yarn of same count prepared from heavier fibers say viscose.

That means, these 2 yarns; their fineness or count are same but their size will be different, one will look larger, one will look smaller but the traditional expression of yarn fineness capital T is not able to talk about this that means, when we compare the size of yarns, it is better we use this expression V / L not T, what is V/L? V / L = T / rho that means, if 2 yarns are given if we know their fineness and also if we know the fibers which were used to prepare those yarns, so we will calculate this ratio very simple T / rho.

Then numerically, higher value of this ratio, size of that yarn will be higher, larger and just now, you have seen that this S = T/ rho and T / rho = V / L that means, substance cross sectional area is a very important quantity which we will talk about yarn size or size of yarn in a geometrical manner, so that is the importance of substance cross section area of yarn that means, if somebody will ask there are 2 yarns which size is larger?

Quickly, you need to calculate capital S, how; T / rho then the yarn which will have higher value of capital S will be larger than the yarn which will be having smaller value of capital S which will be smaller, so what we learnt now is that yarn fineness is probably not a good characteristic to compare size of yarns, substance cross sectional area is a better quantity to characterize the size of yarn.

So, by now in this module, 2 characteristics we have discussed, 1; yarn fineness, second; substance cross sectional area of yarn, third we are going to speak about substance diameter here D is not substance diameter but D is yarn diameter then what is substance diameter?

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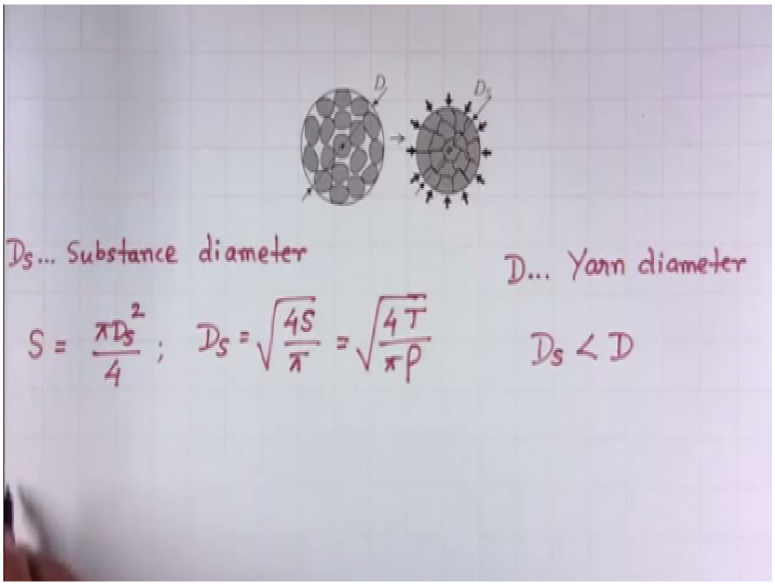

So, we are going to speak about substance diameter, these 2 terms substance cross sectional area of yarn, substance diameter of yarn, these 2 terms were probably first coined by Johansson, he was a scientist devoted his life in solving problems relative yarn structure, he coined for the first time these 2 terms, these 2 terms we often do not speak about however they are very, very important for theoretical understanding of yarn structure.

So, let us come back to this what is substance diameter, you see here 2 images; one, the typical cross sectional; cross section of yarn whose diameter is capital D, so capital D is yarn diameter okay. Now, let us compress this yarn from all sides, isotopically, so that the air which was present inside the yarn is completely removed, so we are going to compress this cross section. so that the air is completely removed.

Then probably, we will find out an image which will be looking like this, so there is no air, all fibers are touching each other here, the image is circular and the diameter of the circle is Ds, so here Ds is called substance diameter. How will you find out substance diameter, what is the area? This area = capital S, substance cross sectional area and the circle so, pi times Ds square/ 4, so Ds is root over 4 times S/ pi and what is S?

S is T / rho, so all are measurable quantities, capital D yarn fineness is very easy to measure, rho; fiber density is also possible to measure, so Ds is possible to determine substance diameter, right. Now, in all practical purposes substance diameter of yarn is smaller than yarn diameter really on diameter in all practical cases, right. So, we will now introduce a relatively new term called relative fineness.

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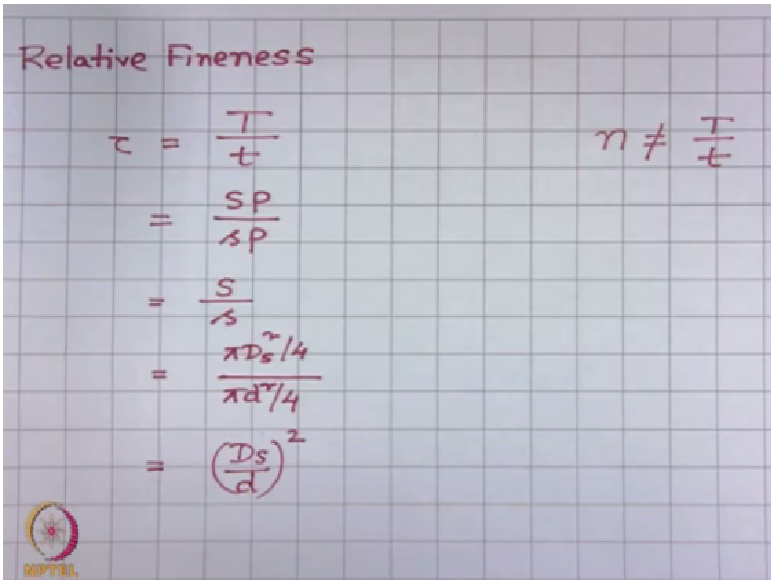

Fineness, everybody knows, what is the relative fineness; relative fineness, we define by the ratio of yarn fineness by fiber fineness, so yarn count direct system divided by fiber linear density, some of you may think at this moment that capital by; T/ small t is the number of fibers present in n cross-section is not it, probably during your undergraduate course, you have learned this expression.

Number of fibers present in yarn cross section is equal to yarn count direct system in tex divided by fiber fineness in tex, is not it, this is not correct, why, they are not; why it is not correct? Because fibers in yarn are not straight, they are inclined at some angles so, if you calculate number of fibers from this expression and if you measure actually number of fibers in yarn by using some cross section cutting technique, you will find that this number will be always higher than experimentally determined number of fibers in yarn cross section.

We will speak about this today in a little deeply, so that is why we call this expression by relative fineness now, let us further work on this expression in order to know more about this. What is capital D? Capital D is substance cross sectional area into fiber density, we have just now derived and in the last module, we have derived that small t fiber fineness is fiber cross section area into fiber density.

So, what do you obtain; capital S/ small s, now what is capital S; pi Ds square/ 4 divided by pi d square / 4, what is Ds; substance diameter of yarn and what is small d; diameter of fiber, so we finally obtained this expression, right, okay. We will answer to this question, if this is not true then what is true that means, how do we find out number of fibers present in cross section of yarn, we are going to answer this question.

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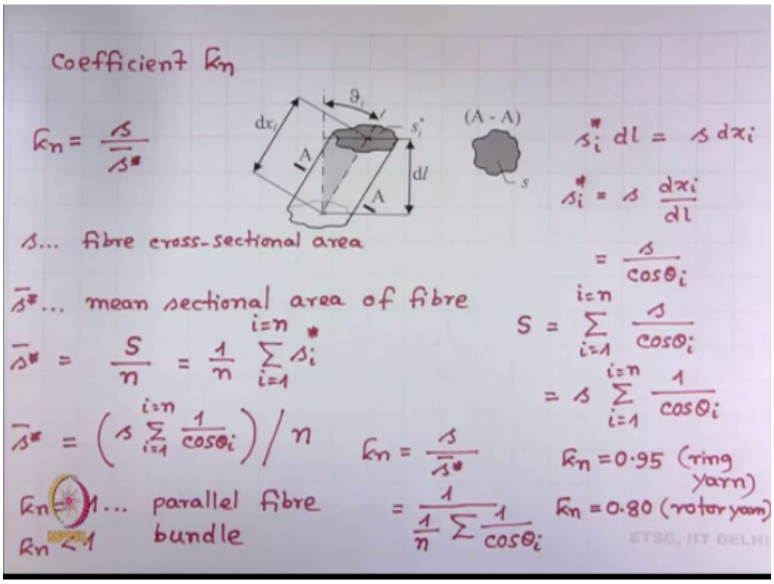

But before that we need to understand about one more important characteristic of yarn structure which is known as coefficient kn, it is another relatively new term probably for you, coefficient kn, what is coefficient kn? kn is a coefficient we define it by a ratio of fiber cross sectional area, small s is area, this you know from first module and what is this term; this is mean sectional area of fiber.

How to find out it, what was the total sectional area, capital S divided by n, what was capital S; we have already derived it, is not it, so the definition of coefficient kn is probably clear, it is a ratio of cross sectional of a fiber to the mean sectional area of fiber, how to find out mean sectional area; substance cross sectional area of yarn divided by number of fibers present in yarn, this we do not know yet.

Well, now let us find out an expression for kn, what you see here; 2 images is not it, this image what is this; this is basically scheme of a fiber which is inclined at an angle theta I from yarn axis, there could be n number of fibers we are talking about one general fiber that is why we use this subscript I, I can be 1, I can be 2, I can be n, I can be any number, so this general fiber; ith fiber is inclined at an angle theta i from yarn axis okay.

Now, this fiber has a sectional area S subscript i superscript star and we use 2 quantities, dl is this length and dxi is this length, what is this image; in this image, we express the cross sectional area of the fiber that is s, so if the fiber is inclined if you cut along this you get sectional area but if you cut perpendicularly along this, you get cross sectional area s, is that clear.

Now, what is the volume of ith fiber; volume of ith fiber is section area * perpendicular height this is = the cross sectional area * perpendicular height, these 2 will be equal because both are volume of the same fiber, so s * dxi/dl, what is this? This is equal to cos theta i, so this cos theta i = dl/dxi, right then, what is capital S? Capital S is the sum of all these areas for n fibers, so summation i = 1 to n s/ cos theta i, s is a constant; it can come out of the summation, right.

Now, so we come back to this expression now, s star is s/n, so this is s divided by n, right so what is kn? Kn is from here, s/ s star bar, so if we substitute s star bar here, this s and this s will be cancelled out and as a result, what we will obtain is 1/1/ n summation 1 /cos theta i right, so this is the expression for kn, let us learn more about this expression. So, the quantity kn is the harmonic mean of the inclination angle theta, right.

Well, second; if theta is 0 for all fibers in the yarn that means all fibers are parallel to the axis of the yarn, then it is not a yarn, it is the parallel fiber bundle, so if theta is 0 for all fibers then it becomes a parallel fibre bundle in that case kn will be = 1, so kn will be = 1 for parallel fibre bundle. In all other practical cases kn is <1, right. Now, just to tell you a few facts, kn is typically = 0.95 for cotton ring yarn and kn = typically, 0.8 for rotor yarn okay.

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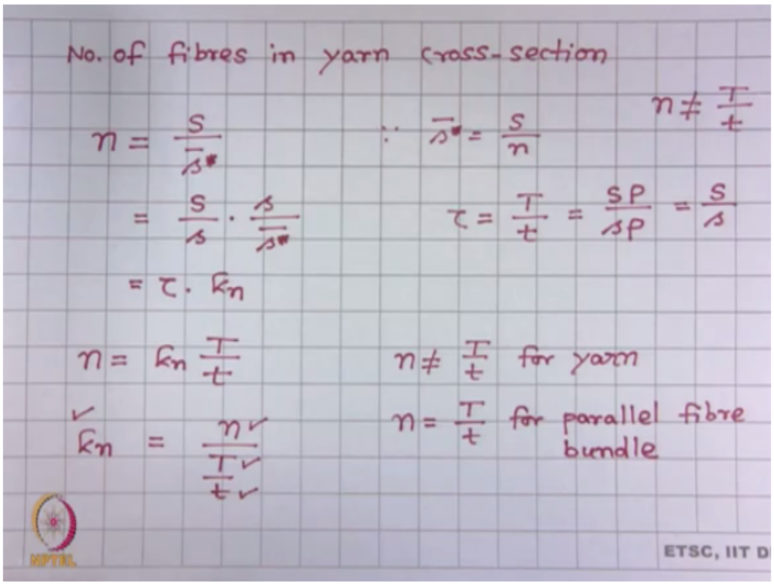

So, coefficient kn is clear now, now we come to another characteristic of yarn that is related to number of fibres in yarn, number of fibres present in yarn cross section, I told you a few minutes before n is != this, then what is the correct expression for n? Let us find it out, n is S/ this, how; we have already used this expression, so n is this, let us now write capital S/ small s * small s / small s star bar, right, you can write it.

Now, what is this capital S/ small s? Capital S/ small s you remember tau is capital T / small t that = capital S * rho, this * rho, so capital S/small s, so this = tau and what is this small s / s star bar? kn, so n = kn times capital T / small t, it is not because kn is < 1 for yarn, if kn = 1 for parallel fiber bundle then, this expression is correct, right. So, I told you if you use this expression to find out number of fibers present in yarn cross section, you will get a higher value.

Then the number of fibers present in yarn determined experimentally right, so now this expression can also be used to find out kn experimentally, how? kn is n / this, if you use; if you cut a cross section of a yarn by using microtome and all other apparatus and put that cross section under microscope, you will be able to find out, you will be able to count how many fibers are present.

So, n you will be able to determine experimentally, capital T, yarn count, yarn fineness, you will be able to determine experimentally, small t, fiber fineness you will be able to determine experimentally that means, these 3 quantities are possible to determine experimentally then by using this relation, you will be able to find out kn, right, so in this manner we will be able to find out coefficient kn and also number of fibers present in yarn cross session.

As I said you typically, kn is very close to 0.95 in case of cotton ring yarns however, because of the disordered arrangement of fibers in rotor spun yarn, kn is equal to; roughly = 0.8, okay. So, now we will go to discuss another important, another very important characteristic of yarn structure that is called packing density.

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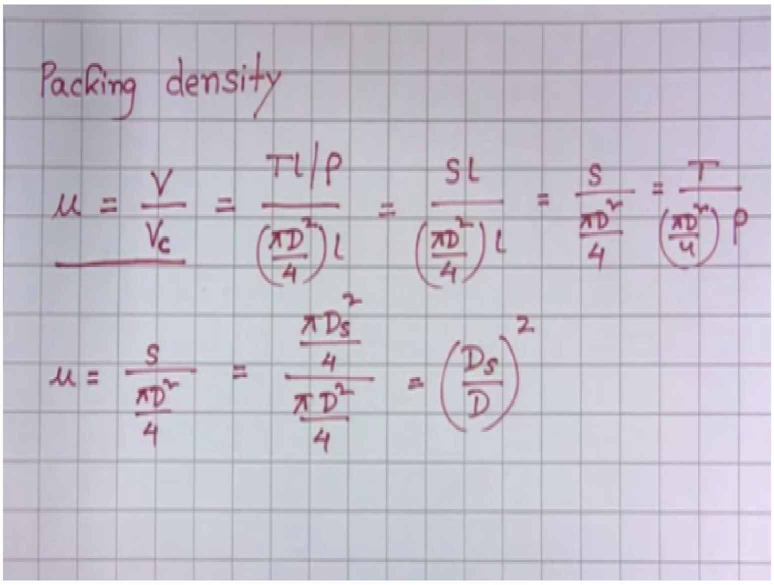

Now, probably I told you that yarn; in yarn structure, we study the arrangement of fibers in yarn, this arrangement is generally expressed, either expressed by fiber packing arrangement as well as fiber directional arrangement. Fiber directional arrangement means fiber inclination from yarn axis, this coefficient kn will be able to speak about fiber directional arrangement, fiber orientation in yarn.

How do we find out fiber packing arrangement, how to characterize fiber packing arrangement in yarn? By using packing density, we can characterize fiber packing arrangement in yarn, what is packing density? We use a symbol mu to denote fiber packing density, fiber packing density is a very, very important characteristic of yarn, we will use in many modules this term, packing density.

Packing density is defined by volume occupied by all fibers in the yarn divided by volume of the yarn, so packing density is a ratio which is defined by volume occupied by all fibers in the yarn to the volume occupied by the yarn itself. Now, what is your V; volume occupied by all fibers in the yarn, in this module we have already learned V / L = T / rho, so V = T times L / rho and what is Vc?

Vc is pi D squared/ 4 * L, if we consider yarn is cylindrical, we often consider it right now, what is T/ rho; T / rho = capital S, also we have learned, so T / rho is capital S * L, so this L, L will cancel out, we will obtain S/ pi D square / 4 now, what is S? S is T / rho, so T pi D square/ 4 * rho right, so mu = S/ pi D squared further, we can write it as pi Ds square/ 4/ pi D square/ 4, so Ds/ D whole squared, so this is an expression for Mu.

So, Mu; Mu is defined by this expression, volume occupied by all fibers in the yarn divided by volume of the yarn, we can; if we know this expression Ds and D, we also will to find out what is Mu. Now, we would like to learn packing density a little more, this is a very important characteristics of yarn structure we are going to use it in many modules, we should have a more feeling for this term packing density.

Now, let us learn this term a little more now, in fact this term packing density is probably very important for almost all textile materials be it a monofilament or Sliver or yarn or woven fabric knitted fabric, normal fabric very important term.

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Group	Fibrous assemblies	μ [1]
Linear textiles	Monofilament	1
	Limit structure	0.907
	Combed cotton yarn	0.5 to 0.6
	Carded cotton yarn	0.38 to 0.55
	Cotton roving	0.10 to 0.20
	Sliver	about 0.03
Other textiles	Woven fabric	0.15 to 0.30
	Knitted fabric	0.10 to 0.20
	Cotton wool	0.02 to 0.04
Other materials	Earthenware	0.20 to 0.23
	Wood	0.3 to 0.7
	Animal leather	0.33 to 0.66

So, this table gives you an idea of the level of packing density in different textile materials, in monofilament there is no air practically, there is no air so, packing density of monofilament is 1, limit structure we will come a little later, combed cotton yarn; packing density range is from

0.5 to 0.6, carded cotton yarn; packing density ranges from 0.38 to 0.55, what is the packing density of roving; cotton roving?

Lot of air is present, packing density ranges from 0.1 to 0.2, what about sliver, what is the packing density of sliver, a very porous object, packing density is typically around 0.03 for roving, what is about Woven fabric; packing density of woven fabric is 0.15 to 0.3, knitted fabric typically ranges from 0.1 to 0.2, cotton wool is a medical product, we often used to cover a wound, packing intensity ranges from 0.02 to 0.04.

Some other materials just to compare where our textile material falls, Earthenware; 0.2 to 0.23, Wood; 0.3 to 0.7, Animal leather; 0.33 to 0.66, so this is a table which gives you ideas about the packing density in different materials. Now, packing density now if somebody will tell you packing density of this yarn is around 0.5, what do you infer from this information, you will tell that from definition, 50% of the volume is occupied by fibre, 50% of the volume is occupied by air very good, correct.

Can you speak something more on this, can you talk about the arrangement of fibers inside the yarn, a little difficult, let us a bit try, what do you see, meaning of; structural meaning of packing density? Now, probably you have heard during your undergraduate course, hexagonal packing arrangement, hexagonal model of fiber packing arrangement in yarn, so we will use a model of fiber packing to know more about this term packing density.

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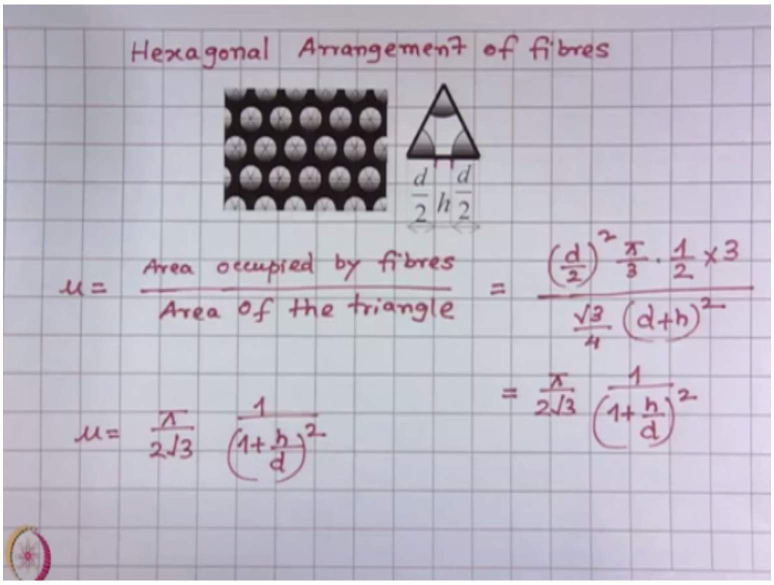

So, circular fibers, let us assume, let us imagine that circular fibers are arranged in an hexagonal manner in a yarn so, this is typically hexagonal arrangement and its unit cell is a triangle which is shown here now, what is the packing density of this structure, if we are able to find out the packing density of the unit cell that will be equal to the packing density of this structure because this structure consists of this unit cell, so is an equilateral triangle.

So, this equilateral angle packing density you will be able to find out area occupied by the fibers by area of the triangle, what is the area occupied by the fibers? So, this is the area of this sector, there are 3 sectors, so this is the area occupied by the fibers and what the formula of equilateral triangle * d + h, this is the base, so you see that square, right yeah, so what is h; h is the distance between 2 fibers and d is diameter of fiber.

Now, so this is the expression for packing density in hexagonal packing arrangement now, in the next class we will find out 4 variants of this arrangement by considering different values of h, we will try to find out packing density of those 4 variants and then we will be able to find out which is typical variant for yarn because we know yarn packing density ranges from roughly 0.4 to 0.6.

So, which of these variants follow yarn structure we will be able to know also, we will be able to know what is the meaning of packing density 0.5 or 0.4 or 0.6, so in the next class, we will do that thank you, thank you very much for your kind attention.