Textile Product Design and Development

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Lecture - 27
Pressure Garment Design

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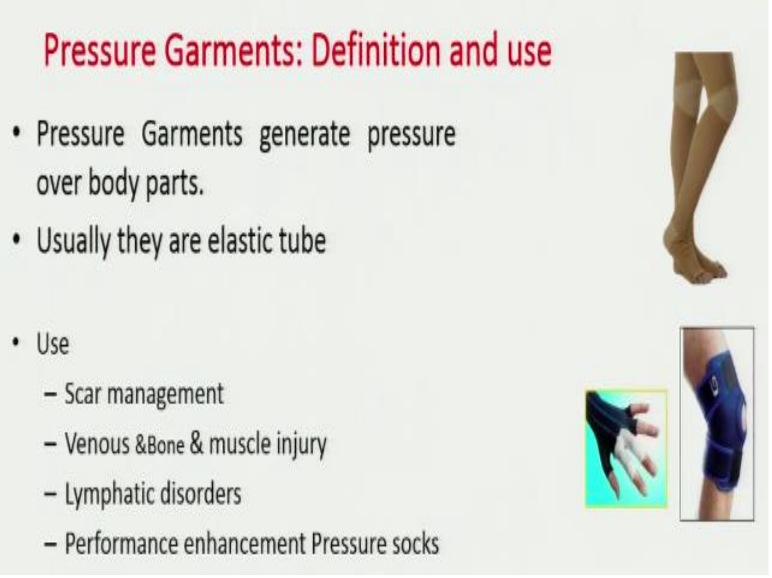

Today's topic is pressure garment design. What is a pressure garment? Pressure garments generate desired pressure over body parts where we want to wear them. Generally, they are elastic tubes, but they can also be made from elastic fabrics.

These garments are used for scar management, venous and bone and muscle injury, lymphatic disorders, and performance enhancement pressure socks. The pressure garment is required for players to reduce their fatigue.

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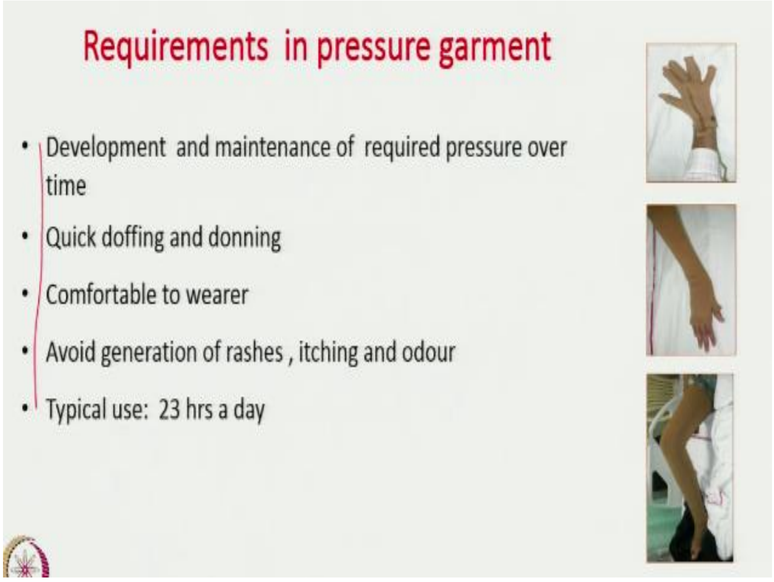

The very first requirement in a pressure garment would be the development and maintenance of the required pressure over a certain period. The span of time can vary from person to person depending upon the induce. So, we must ensure that the garment can develop a certain level of target pressure, and the pressure should be maintained over a certain period, depending upon the use. In some cases, it could be a few hours, and in some other cases, it could be several hours.

The next requirement is quick doffing and donning; it should be able to easily don and doff. The third important requirement is comfort; it must be comfortable to the wearer, which means that the wearer should not get rashes or any itching tendencies or any bad odour. The typical use of pressure garments in some cases could be even 23 hours a day, and even it can go up to months.

So, the duration of use can be from a few hours to a few days also, and the garments should fulfil all these requirements, while the most important requirement is the pressure that is required.

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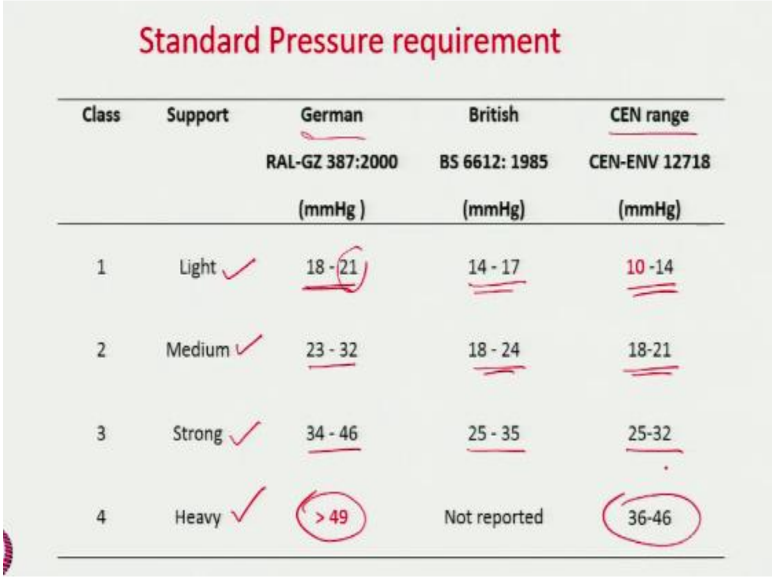

Class	Support	German RAL-GZ 387:2000 (mmHg)	British BS 6612: 1985 (mmHg)	CEN range CEN-ENV 12718 (mmHg)
1	Light	18 - 21	14 - 17	10 -14
2	Medium	23 - 32	18 - 24	18-21
3	Strong	34 - 46	25 - 35	25-32
4	Heavy	> 49	Not reported	36-46

Certain standards by the German, British and CEN for pressure garments are shown in the slide. They have classified the pressure garments depending upon the level of pressure that they generate into light, medium, strong and heavy pressure garments. For light garments, according to German standards, the pressure varies between 18 to 21 mmHg. British standard describes that it is between 14 to 17 mmHg. According to CEN standards, it is between 10 to 14 mmHg.

Though there is a variation between the standards, roughly, we can say that the lighter pressure garments can generate a pressure between 10 to 20 mmHg. 10 mmHg is the minimum, and 21 mmHg is the maximum in that range. The medium pressure garments are shown as 23 to 32, 18 to 24, and 18 to 21 mmHg, respectively, for German, British and CEN standards. Similarly, for strong pressure garments, it is 34 to 46, 25 to 35 and 25 to 32 mmHg, and very heavy pressure garments can generate pressure of more than 49 mmHg.

According to CEN standards, the pressure generated varies between 36 to 46 mmHg. These data give us an idea of what level of pressure is expected and how the garments are classified according to the level of pressure that the garment can generate.

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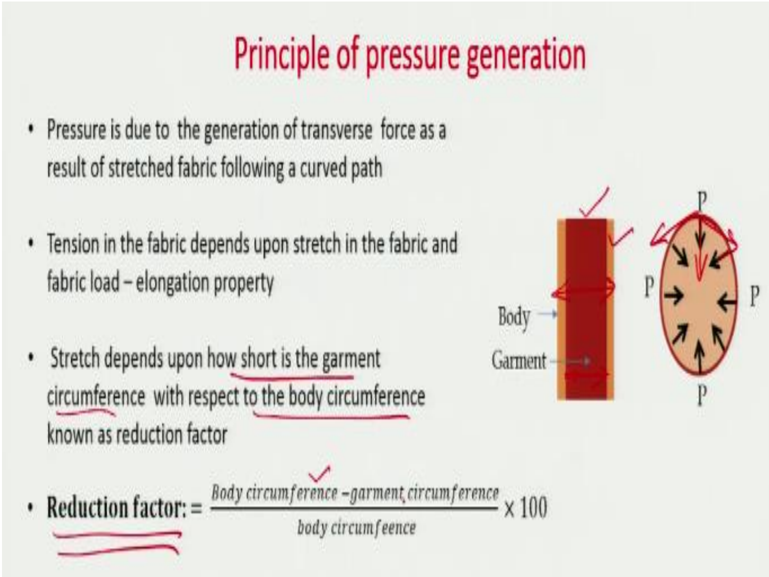

Principle of pressure generation: how is pressure generated by the garments? Pressure is due to the generation of transverse force because of stretching of the fabric or the stretched fabric following a curved path or must have a curvature. As shown in the slide, the body outside the cylindrical garment is schematically shown. The inside one is the dimension of the garment. It is not that the garment has gone inside, but typically, the garment dimension is less than the dimension of the body.

As a result, the garment compresses the body part over which it is covered. Due to the compression, there must be some amount of stretch in the garment because the garment is slightly smaller in size when compared to the body. So, if we place the garment over the body, which is a little bigger in size, the garment gets stretched. It means that the garment or the fabric is under tension, and because of this tension, transverse force will be generated.

So, tension development depends on the level of stretch in the fabric and the load-elongation behaviour of the fabric, i.e., stress-strain behaviour. The elongation decides the amount of force generated in the fabric. Stress development depends on the garment circumference with respect to the body circumference and is defined by a factor called the reduction factor.

$$Reduction\ factor = \frac{Body\ circumference - Garment\ circumference}{Body\ circumference} \times 100$$

the garment circumference is less than the body circumference.

So, in pressure garments, the garment circumference is always slightly shorter than the body circumference. Typically, the reduction factors are 10 to 20%. The reduction factor varies with respect to applications and the material that is used. Ultimately, a certain amount of force must be generated, and the force is a function of the stretch of the fabric. Therefore, it depends upon applications. The force requirement in the fabric may differ based on the material that has been used in making these fabrics.

Generally, we use elastic fibres or in some cases, we use elastic threads that have considerable elongations. The filaments are generally polyester or nylon. These filaments are slightly more extendable than normal cotton fibres. So, if we use them without any elastic fibre, then the force development is much less. In some cases, we may use them so that they just sit on the skin or on the body part and generate a very light force.

So, in many cases, we do not use any extra elastic fibres; we simply use a filament, polyester filament, and nylon filament. Sometimes, the filaments may also be textured, and we can directly use them to make a garment and put it on the body. The pressure garment should not only develop pressure, but also it should be able to sustain the pressure over a long period of time, i.e., pressure should not decay much over time.

The other factor is that the recovery part, when it is not worn, the fabric should be able to recover to its original dimensions. So, it is not only the stretching behaviour which is important; it is also important that it should be able to recover when the stretch is not there on the garment or on the fabric. When we remove the pressure garment from the body and allow it to relax for a certain period, maybe over a day, then we would expect that the garments would come back to its original dimensions.

So, recovery property is also equally important, and hence, keeping in mind these two while designing pressure garments, i.e., stretch, the force required to stretch it and recovery when stretch is not there. As stated earlier, the other significant consideration is stretch decay; when the garment is removed, the pressure should not gradually decline or decline a bit and then remain stationary. So, these are the important aspects and keeping in mind these aspects, and accordingly we must choose the right materials.

There are not many raw material and structural options available because only a few elastic fibres or elastic structures are available; it could be rubber filaments or elastomeric fibres. The structure that gives natural stretch, most of them are knitted structures and the fibres which have good stretch behaviour on their own are either nylon or polyester. So, these are the kinds of fibres that we can use, and then we can have different structures, knitted structures, and sometimes woven structures also can be used because we can make a stretchable woven fabric also.

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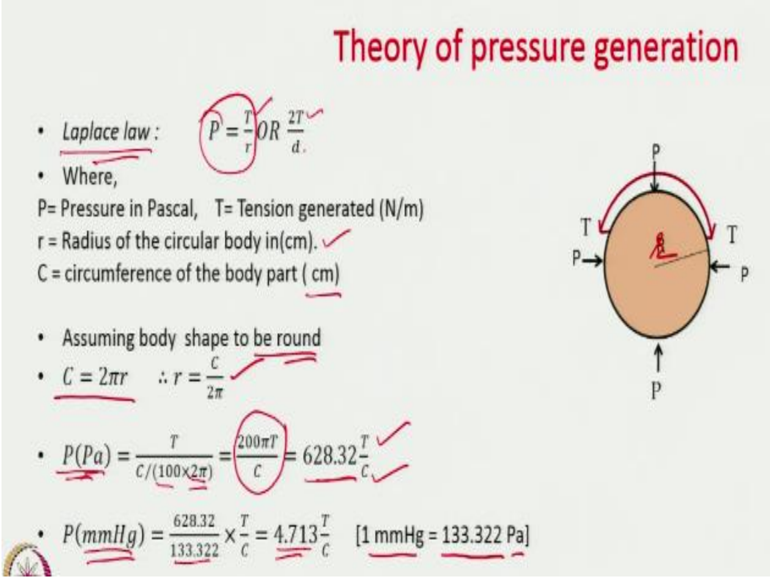

The basic theory of pressure generation: according to Laplace's law, pressure is,

$$P = \frac{T}{r}$$

this equation is very popular, and the pressure is related to the tension in the fabric and the radius of the circular body if the body part is assumed to be circular. It is not necessary that all the body parts are circular. Most of them may not be perfectly circled, but for the sake of simplicity, we assume that the human body parts are mostly circular in nature.

In that case, the Laplace law will be valid; '$P = \frac{T}{r}$', or it will be '$\frac{2T}{d}$' where 'd' indicate the diameter of the circular body. As assumed, the body shape is round, and the circumference and the radius are related as,

$$C = 2\pi r$$

Therefore, 'r' becomes '$\frac{C}{2\pi}$'.

So, the pressure develops is,

$$P\ (Pa) = \frac{r}{C\ /\ (100 \times 2\pi)}$$

Where 'r' is in centimetre, 'C' is also in centimetres. So, centimetres can be converted into meters by dividing 100. So, it becomes,

$$\frac{200\pi T}{C}$$

that simplified to '$628.32\frac{T}{C}$'. The unit of pressure is 'Pa' when the tension is in 'N/m' and the circumference is in 'cm'. If we want to convert 'Pa' to 'mmHg', which is mostly reported in the case of pressure garments, then we must establish a relationship between these two. The relationship is that 1 mmHg is equal to 133.322 Pa. Therefore, if the pressure is in the Pascal unit, we divide it by 133.322, which gives '$4.713\frac{T}{C}$'.

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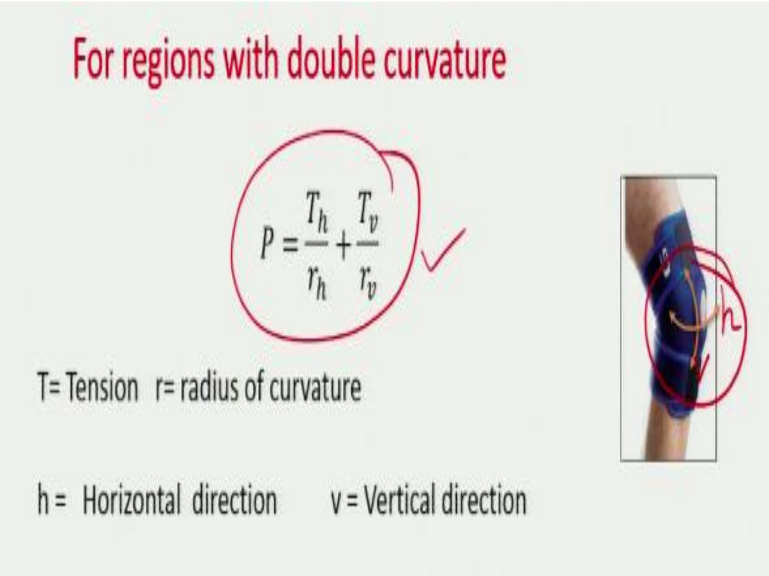

There are certain regions of the body part where the body part has double curvature. Many parts of the body have double curvatures, and one of the very common examples is the knee area. So, the curvature along the knee and around the knee are not the same, they are different. Therefore, if we put a circular fabric or garment over the knee, then the tension or stretch that develops will be different in the horizontal and vertical directions. The pressure developed in the case of curved surface is,

$$P = \frac{T_h}{r_h} + \frac{T_v}{r_v}$$

where 'v' indicates vertical direction, and 'h' indicates horizontal direction.

So, we must consider the stretch in both directions to get the value of pressure that develops around the curved surface. So, this equation is very useful, and we can estimate the stretch in the fabric. If we know the stretch, then we can find out how much tension is developing in that stretched fabric which depends on the elastic property of the fabric.

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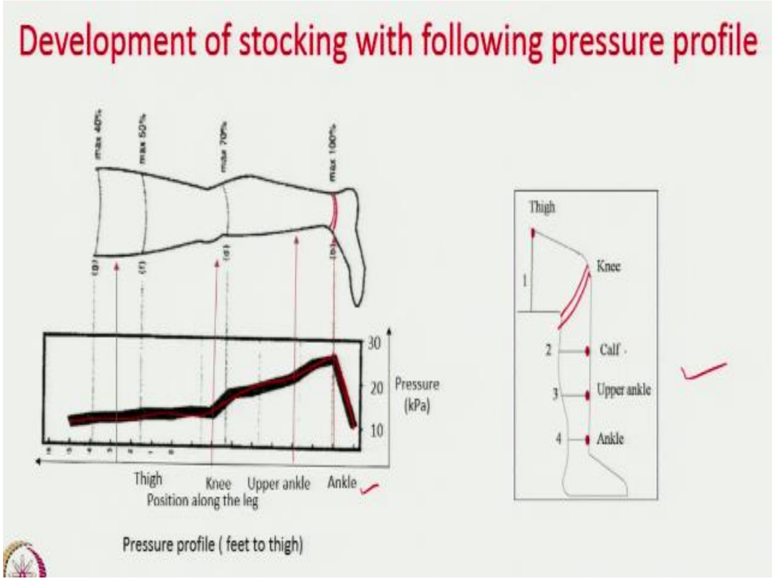

An example of the development of stocking with the following pressure profiles is shown in the slide. The pressure requirement in stocking is shown in the top image, and the pressure profile is shown in the bottom image. The solid black line in the graph represents the requirement of pressure along the leg, starting from the ankle to the thigh region. It is observed that the maximum pressure requirement is there near the ankle.

From the ankle region, the pressure gradually reduces. Beyond the ankle over the feet, the pressure again is declining. If this is the pressure profile that we require for stocking, the question arises, how do we develop a structure which gives this kind of pressure profile? The diagram on the right-hand side shows the position of the ankle, upper ankle, calf, knee and thigh.

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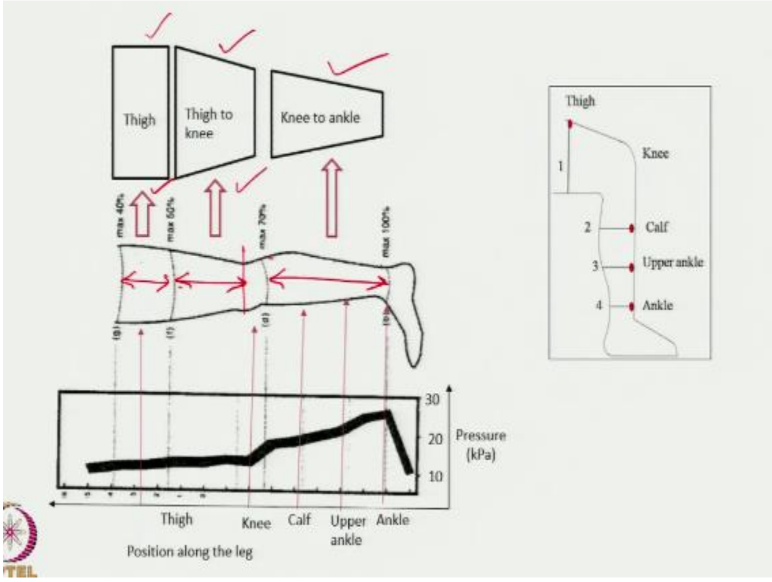

In the diagram shown in the slide, the leg portions are divided, starting from the thigh to the feet, into broadly three regions. One region is the thigh region, as shown in the diagram; another region is the thigh to knee region, and the third region is from the knee to ankle. So, the entire garment can be divided into three regions. We assume the geometry of these regions. The thigh is nearly circular, and the corresponding fabric that we need to cover develops pressure and looks like a rectangle, as shown in the figure.

The next region, which is thigh to knee, is like a slightly conical shape based on the pressure requirement. Therefore, the fabric that covers the thigh to the knee region is slightly conical in shape. Similarly, we can assume for the third region as well. From the knee to the ankle, another piece of fabric will be required which is again conical shape. So, these are the very simplified ways to make the case simple, and the entire garment part is made of three regions; one is perfectly round, and the other two regions are a little conical in nature.

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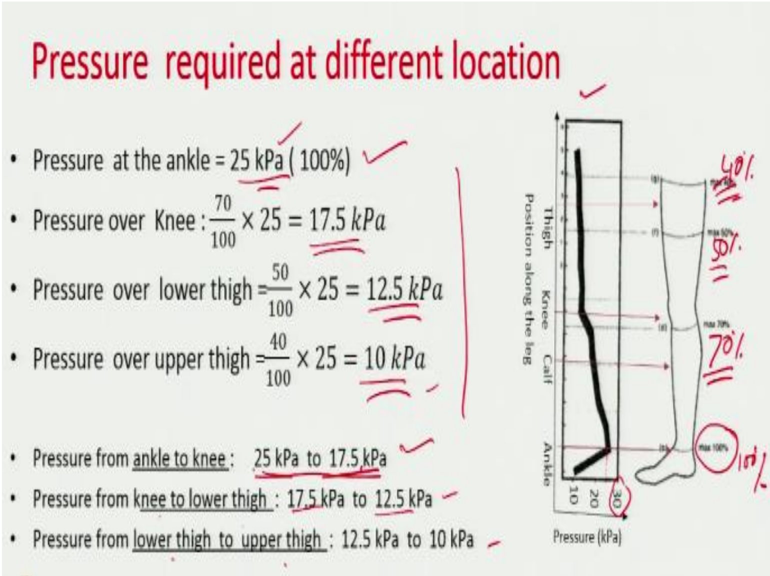

The numerical value of pressure requirement at different locations is stated in the slide. From the diagram, the pressure requirement at the ankle region is 25 kPa. With respect to the pressure requirement at the ankle region (considered as 100%), the other regions are also stated. The maximum is 100%, which is at the ankle region. The pressure over the knee region is 70%, and for the lower thigh, it is 50%. For the upper thigh region, it is 40%. From the ankle region, the required pressure gradually reduces.

At the knees, it should be around 70%; then, from the knee, as we move towards the upper part of the thigh, it comes to 50% of the pressure required at the ankle and at the upper thigh region, the requirement is 40%. Then, again, the pressure should gradually reduce. So, what do we need? A graduated reduction in the pressure requirement, not that the pressure should be uniform from ankle to thigh.

At the ankle, maximum pressure is required, and as we go up, the pressure requirement gradually reduces. So, if the pressure at the ankle is 25 kPa, the pressure over the knee region is 70% of 25 kPa, which is around 17.5 kPa, and the lower thigh region is around 12.5 kPa (50%). The upper thigh region is 40%, so it is around 10 kPa. The stocking design is such that it produces a maximum pressure of 25 kPa near the ankle and a minimum pressure of 10 kPa in the thigh region.

As discussed earlier, gradual reduction in pressure is the requirement and for many circumstances, we need not just a constant pressure over the limb, but we need a graduated pressure. In this case, the pressure from the ankle to the knee is varying from 25 to 17.5 kilopascal. So, if we divide the leg into regions like ankle to knee, knee to lower thigh, and lower thigh to upper thigh, then in different regions, the pressure requirements are stated in the figure.

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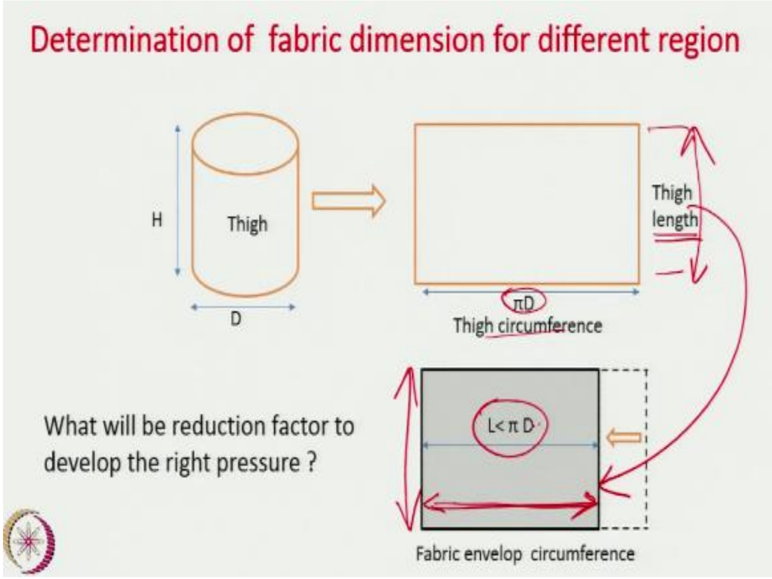

Determination of fabric dimension for different regions: let us consider the thigh region as an example, which is a perfectly round shape. The thigh circumference and thigh length are shown in the slide. Let the garment resting on the thigh be cut and opened; the actual thigh circumference and thigh length are shown in the image shown on the right-hand side. The fabric envelope that needs to be covered over the thigh will be shorter than the actual thigh circumference because we need a certain amount of stretch to develop.

So, the fabric length 'L' must be less than the thigh circumference, which is 'πD'. So, if we want to cover the thigh region of the leg with the pressure garment, it must be rectangular in shape. The length of the fabric would be less than the circumference of the thigh, as discussed earlier.

The width of the fabric piece is equal to the thigh length; both should be the same. However, the length of the fabric covering the thigh must be less than 'πD'. The question that comes how much should be the reduction in the length of the fabric so that we can develop the required pressure in this region? What is going to be the reduction factor to develop the right pressure?

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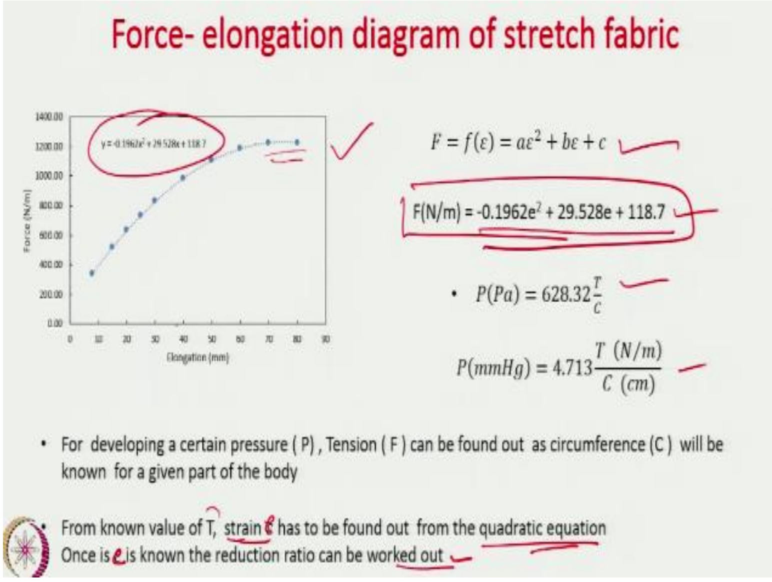

The important aspect is what is the fabric that should be used to generate the required pressure. Let us say we have two or three different fabrics, then we should first understand the force elongation diagram of each fabric. In this case, it is stretchable fabric. A typical force elongation diagram of a stretch fabric is shown in the slide. Every force-elongation diagram can be represented in the form of an equation which has been fitted to describe the change in force with elongations.

A quadratic equation is stated, and 'e' stands for elongation. As the force is applied to the fabric, the elongation increases and levelling off for an elastic fabric. Next, from the known value of tension 'T', the elongation 'e' can be found out from the quadratic equation. The force 'F' is equivalent to the tension 'T' developed in the fabric.

So, once the value of 'F' is known, the value of elongation 'e' can be calculated from the quadratic equation. From the calculated value of 'e', the reduction factor ratio can be found out easily.

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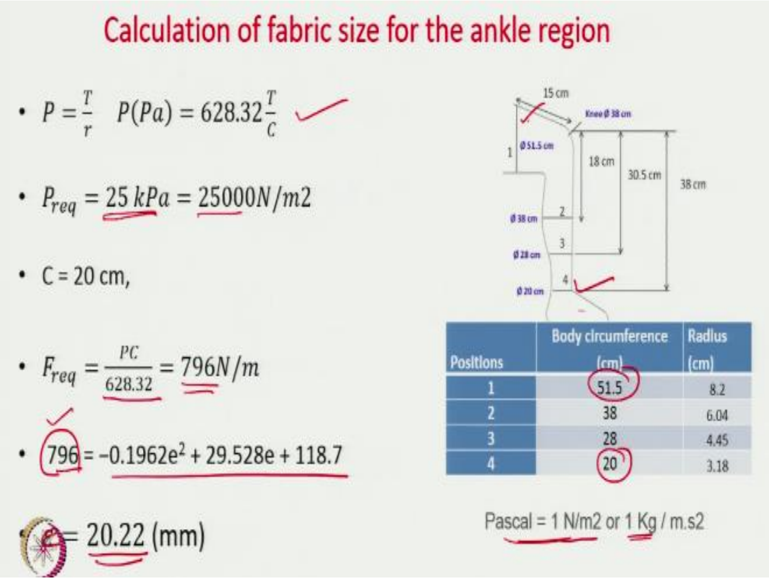

Next is the calculation of the fabric size part. The schematic diagram of the leg, along with the dimensions, are also given of different parts. The thigh part is indicated as position one. In a sequence, finally, the ankle part is indicated as position four. The circumference of the ankle part is 20 cm, and for the thigh, it is 51.5 cm. One can take many readings of the dimensions, and it is based on the individual who is designing it.

For instance, we have taken here just four readings. The required value of pressure 'P' is already known to us. Let us say the pressure that we require at the ankle is 25 kPa as per the pressure profile we have already seen. So, we must develop this much pressure at the ankle region. So, 25 kPa means 25,000 N/m^2.

How much is the circumference 'C'? The circumference of the ankle is 20 cm. How much force do we require?

$$F_{req} = \frac{PC}{628.32}$$

After substitution and simplification, we get the required force to be around 796 N/m. The meter in the unit of required force indicates the width of the fabric, not the thickness. After calculating the required force, we substitute the obtained force value in the quadratic equation.

By solving the quadratic equation, we get the required elongation. If we solve this equation using Excel, we get a value of 20.22 mm, which is the required elongation of the fabric. So, it all depends upon the nature of the fabric. The conversion between Pa and N/m^2 is also given in the slide. One Pa is 1 N/m^2, which is equal to 1 kg/m s^2.

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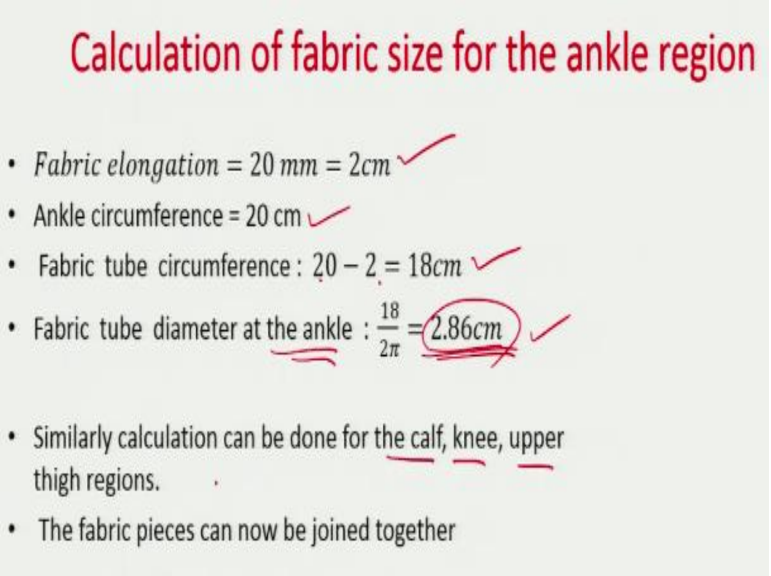

We have already calculated the fabric elongation, which is 20 mm, i.e., 2 centimetres. The circumference of the ankle is 20 cm. So, the fabric tube circumference must be '20 – 2', that is 18 cm. So, the fabric tube circumference must be 2 centimetres less. So, the diameter of the tube is '$\frac{18}{2\pi}$', that is 2.86 centimetre. So, we found out that the ankle region should have a tube of diameter of 2.86 cm for the fabric that we have chosen.

If the fabrics are different, then the load elongation diagram will be different, and therefore, we will end up with some other value. Suppose the fabric is easy to extend, then the fabric to be deformed in that case is less. But one important thing also to know is that there is a minimum extensibility that is required if we want to put on a tube over the knee or calf regions. So, there are different ways; if it is just a tube, the way the tube is worn is such that we must stretch it out and then insert our feet, and then it has to be pulled up.

So, a minimum amount of stretching has to be done simply to push the feet into it and then pull it so that we can wear it easily. If that stretching is too difficult, we need a lot of force to stretch it because a minimum stretch is required in order to insert the feet, that stage itself is so difficult for us. Then, that will also not be a good kind of design because it causes discomfort during the wearing process.

So, if the requirement is such that I need high force, but I do not have a fabric which can give that high force. At the same time can be stretched to the extent that the feet can be inserted easily. Sometimes, there could be a clash, i.e., these two requirements may conflict with each other. In that case, we must think of an alternative type of design where the wearing of this stocking should not be from the feet towards the thigh, but it has to be done in a different manner.

We can have a cut at the middle, and it can be simply placed over the region of the body, and there has to be some other arrangement to tighten it using velcro type of fastening devices or something else like that we have to think of, wearing something just near the knee not necessarily one has to pass the garment through the feet, and they reach the knee. We can have some other design where directly it can be attached to the knee, and we can also have some other type of attachment so that the fabric can be stretched.

In those stretching conditions, it can be fixed around the knee. So, there are different types of design which are possible, and this is just one simple example that we are showing. So, whatever we have done for the ankle region, we can do it for the other regions also: calf, knee, and upper thigh, and then we can get the size of the fabric pieces, and then we can join them together by some stitching technology or some other joining techniques and make the garment which will give us a desired pressure.

So, based on these, prototypes can be designed, and one can then try it out and analyse what the difficulties are that we are facing or whether it is possible to directly knit a fabric tube of the required dimensions or with elastic threads, we can develop the right amount of pressure, and it could be a seamless type of garment can also be thought of by the use of knitting technology.

If we want to use woven fabrics, then we have to cut the fabric into different sizes and then join them together. There are many things about special garment design. There are other aspects as well for designing. Here what has been done is that we are trying to meet the requirements of pressure, but then we have to also see that the product should be breathable.

Otherwise, if something is worn for a long period of time, the moisture accumulates. When the moisture accumulates, then sweating may start, especially in summertime. So, we have to tackle that also. Sweats should not be allowed to accumulate. So, we must think of what we can do so that the moisture that the skin is continually generating the sweat can be taken out by some means, either through absorption or by allowing it to move out to the outside atmosphere.

Then the fabric must be soft also depending upon where it is placed. The seam that we use to join the fabric should be soft as well. Otherwise, it causes a lot of discomfort. So, we must consider the joining techniques, the kind of seam to be used, the thread to be used to join them together, and the selection of fabric other than meeting the stretch requirement. We have to also see from the point of view of moisture vapour transmissions.

The fabric can also lead to discomfort because of the heat entrapment. The body heat also has to escape. Otherwise, the heat accumulates and causes discomfort. Accumulation of heat leads to the development of sweat, which means these garments should also be seen from the angle of the thermal insulation. In winter, it may be beneficial if there is insulation. For summer, it could create problems because in summer, we do not need insulation; we need the body heat to escape.

So, there are other angles one must take care of while trying to design anything, for that matter, which is wearable protection. Continually, one should think of other than meeting the primary requirements; there are other secondary requirements which are equally important because if we do not meet them, the product is not going to sell, and people may reject it after some time. With this, we close this particular session, and we meet again in the next class. Thank you.