Testing of Functional & Technical Textiles
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Lecture - 08
Testing of Transmission Characteristics of Textile Fabrics (contd…)

Hello everyone. So, what we are discussing is the Thermal transmission characteristics through fabric. Till now, we have discussed the transmission characteristics of functional textiles in normal condition, normal activity level. Now, we will try to understand how to measure the thermal transmission characteristics for extreme heat condition particularly.

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So, one of the methods is the Thermal Manikin method. Although, Thermal Manikin is used for measuring the thermal transmission in normal condition; but for extreme condition where human subject is not suggested in those applications we can use Thermal Manikin. This is the picture of Thermal Manikin. So, why do we need to test Thermal Manikin?

So, it is used for testing and product development. Earlier, initially it was used for Building and Automobile industry; for evaluation of performance of heating and ventilation system. Clothing industry also use for developing clothing with improved thermal properties; Performance testing of protective clothing. When we are talking about protective clothing, we talk about the extreme condition and there its uses that improvement in clothing comfort, health and safety in working life.

(Refer Slide Time: 02:38)

So, the salient features of thermal manikins are it simulates the human body the whole body and the local part and it simulates the heat exchange. Number of individually regulated body segments are there are large numbers typically its more than 30 segments and in other methods which we have already discussed, the heat exchange is in 2-dimension, where we keep the fabric in flat condition.

But actually the heat transmission from human body gets transmitted through 3-dimensional mode. So, the Thermal Manikin measures the heat transmission in 3-dimensional mode. It measures the heat loss due to conduction, convection and radiation. So, which simulates the actual heat transmission condition through human body and the manikins are of different types, we can get different types of manikins like walking manikin and stationary sitting manikin, standing manikin. So, and manikin we can place at different climatic condition.

Whole body heat loss is determined by summing up of area weighted value. So, at different portion, the heat loss, heat transmission will be known through different segment different senses and depending on the area at if we can measure the weighted average. So, we can calculate the whole body heat transmission. It can integrate the dry heat loss from human body in a realistic manner. If we test the heat loss in guarded hot plate.

So, we will get 2-dimensional heat loss system which may not actually simulate the real condition which is not realistic one. The value which we get in guarded hot plate or tog meter or any other method are used mainly for comparison purpose. But actual heat transmission we can get through thermal manikin system. It can measure the clothing thermal insulation objectively. So, in subjective method like the wear trial technique, we can sense the thermal insulation and we can rate it by some rating scale. But here we can measure the objective value we can get the objective value of thermal insulation.

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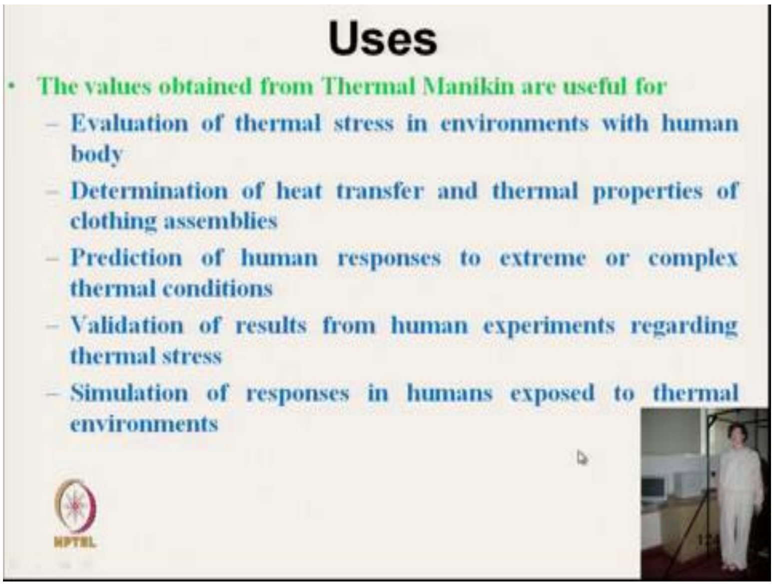

So, this manikins can be used in different ways. The values obtained from thermal manikins are useful for evaluation of thermal stress in environment with human body like at extreme heat or extreme cold, where human subject sometime is actually problem its dangerous. In those applications, we can use thermal manikin and human as subject can actually fill the thermal stress subjectively. We cannot get any objective value. So, in those case, we can use thermal manikin determination of heat transmission and thermal properties of clothing assembly.

So, fabric thermal transmission, fabric as individual flat fabric thermal transmission, we can measure using different techniques; but clothing as an assembly, if you want to measure the thermal transmission, we have to use the thermal manikin. Prediction of human responses to extreme or complex thermal condition so, that we can predict. So, the getting the result from thermal manikin we can predict what could be the human responses validation of results from human experiment regarding thermal stress. So, once we test the human experimentation and we test with the manikin, we can validate the result. Simulation of responses in human exposure to thermal environments.

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Now, we will discuss different other methods for extreme heat and flame protective clothing. So, there are different methods of measurement of heat transmission through fabric and this heat transmissions are not only a particular form, it may be in a flame, may be a radiant heat may be splash water. So, there are different techniques, we will discuss one by one. But in most of the cases, we will talk about the prediction of second degree burn.

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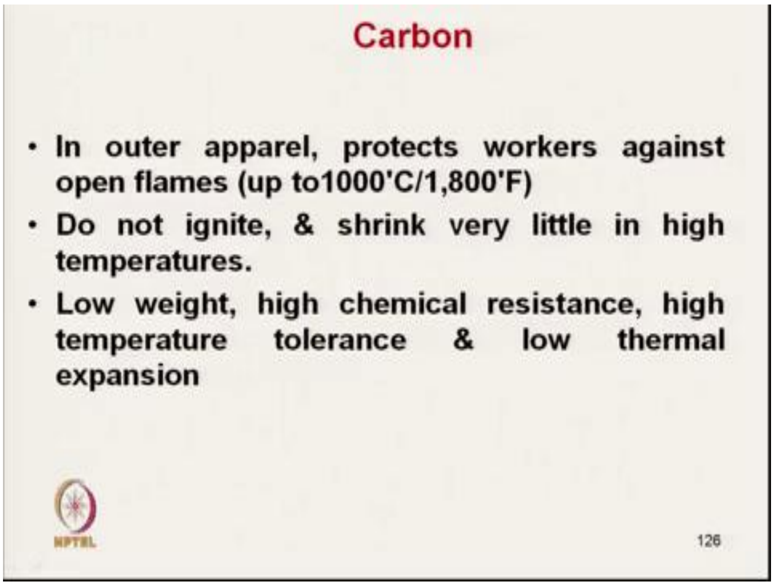

Before we go into the test method first let us try to understand what are the materials which are used for extreme heat protective clothing; carbon fiber is one of them which is used in outer apparel, protects, worker against open flame up to 1000 **°C**.

So, in those applications carbon fibers are used and this fiber, they do not ignite and shrink very little in high temperatures. So, shrinkage is very less in high temperature and they do not ignite. So, due to this characteristic we can use this fiber for open flame and it has got low weight.

So, light weight if we want light weight fabric typically for any performance clothing, we need lighter weight high chemical resistance. So, very high chemical resistance is required; high temperature tolerance and low thermal expansion. So, these are the quality which actually makes the carbon fiber is material which can be used for protection from open flame. Next fiber is Aramids.

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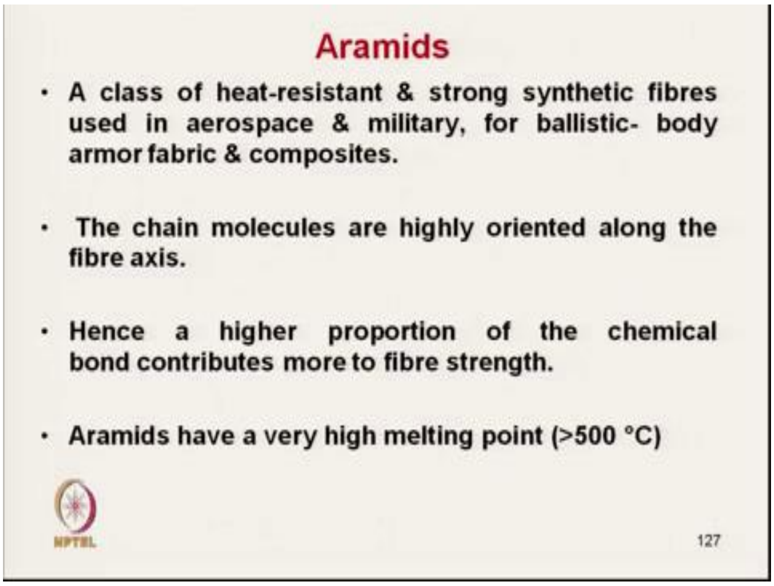

This fiber it is a class of heat resistance and strong synthetic fiber used in aerospace and military application, for ballistic- body armor and composite. The chain molecules are highly oriented along the fiber axis. Hence, a high protection higher proper proportion of the chemical bond contributes more to the fiber strength and another characteristic is that Aramid fiber, they have high melting point which is more than 500 **°C**. So, we can use this fiber for high temperature application.

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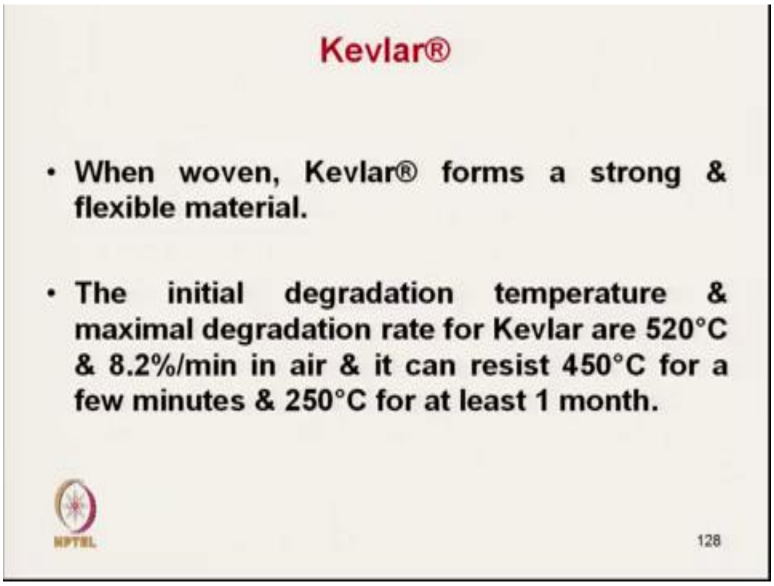

Kevlar; when it is woven, Kevlar form are strong and flexible material.

The initial degradation temperature and maximum degradation temperature, they are actually the rate is that 520 **°C**, it is a initial degradation temperature and 8.2 % per minute in air and it can resist 450 **°C** for few minutes and if we keep this fabric made of Kevlar at high temperature as high as 250 **°C**, it can make maintain its strength atleast for 1 month. So, Kevlar can be used for high temperature application, for longer time.

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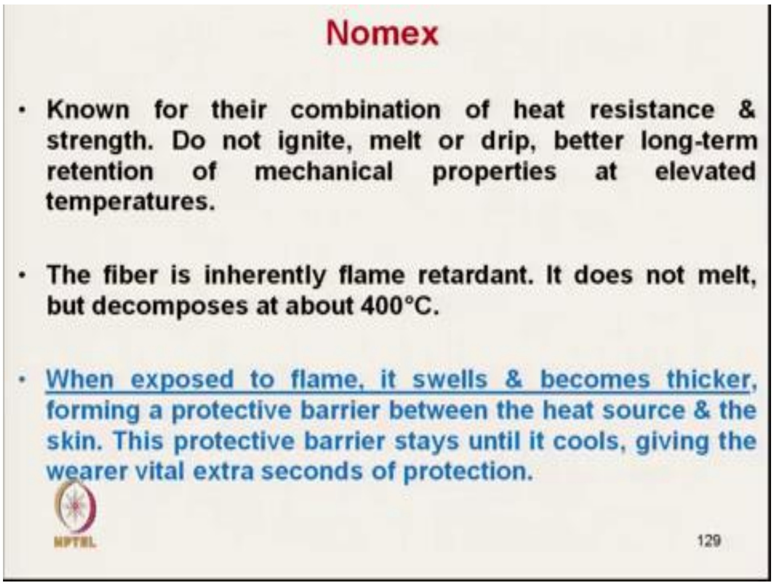

Nomex is one fiber which is very commonly used for flame protective clothing. It is known for their combination of heat resistance and strength. Do not ignite, melt or drip, better long-term retention of mechanical properties at elevated temperature. So, at high temperature, it maintains the mechanical property. The fiber is inherently flame resistant. It does not melt; but it decomposes at 400 **°C**.

So, although it does not melt, but at high temperature like 400 **°C**, this fiber decomposes. So, we can safely use at high temperature which is less than 400 **°C** and when this fiber is exposed to flame, the unique quality of this fabric the unique characteristic of this fabric is that it swells and becomes thicker. So, once we prepare fabric made up Nomex and it is exposed to flame, the fiber itself swells and it becomes thicker.

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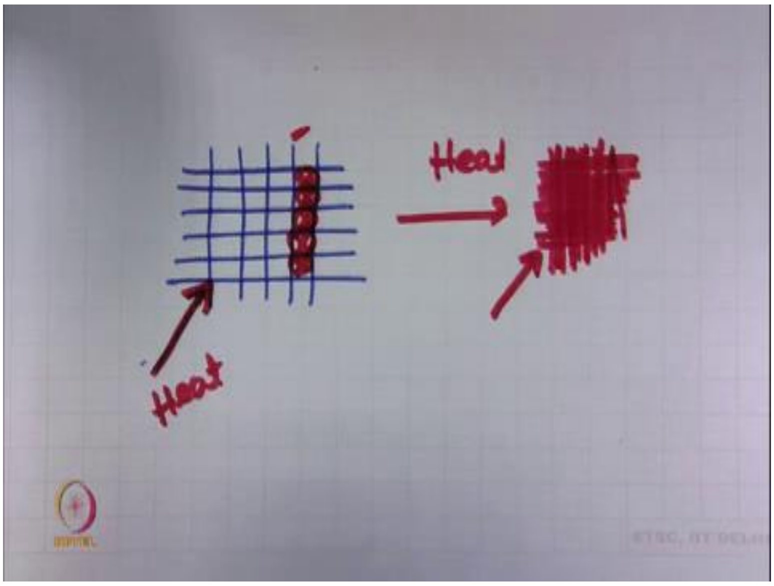

So, you can see here say this is a fabric made of Nomex and this is been heated. Heat is been applied. Once it is heated, this fibers or filament will become thicker and as it is this filaments are thicker. So, this open pores will be blocked due to swelling of the fiber and as this is this openings are blocked, this will enhance the protective performance.

The heat flow through open space, the radiative heat flow through the open space, will be much higher than the compact phenomena. So, when exposed to flame, it swells and becomes thicker forming a protective barrier between heat source and the skin. So, this protective barriers stays until it cools. So, once it is cooled down, again the openings will be created. So, that will give the breathability. But when its exposed to the flame, when you require protection and this gives extra protection, extra few seconds of protection it will give which will prevent from burning.

This is one of the unique characteristic of Nomex.

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Now, international standard for fire protection which is National Fire Protection Association, NFPA which is followed worldwide and the Standard on Protective ensemble for Structural Fire fighting and Proximity fire fighting are Evaporative heat transfer through garments, Thermal Insulation, Durability of Barrier material, Radiant reflective protective area of proximity fire fighting and this NFPA involves in Designing, Performance and Testing and Certification.

So, designing, performance, testing and certification all these activities is done by NFPA and there are standards available NFPA 1971 and 1994.

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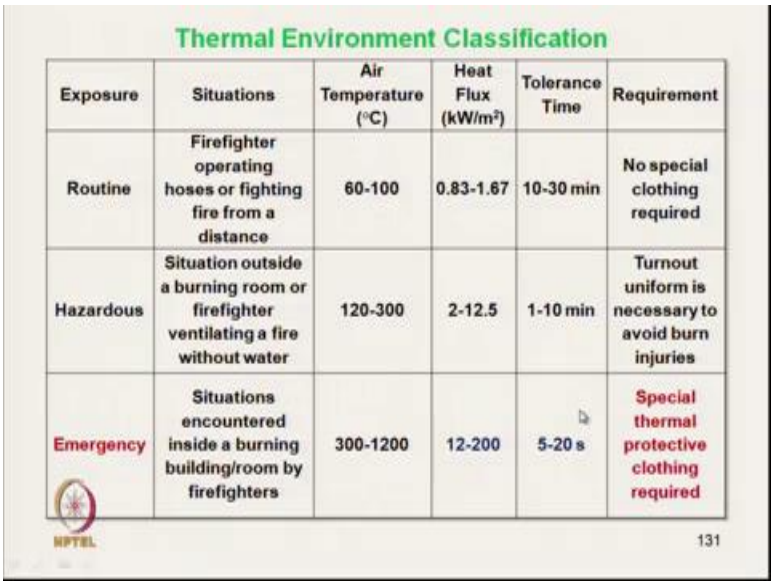

Thermal Environment Classification

Exposure	Situations	Air Temperature (°C)	Heat Flux (kW/m²)	Tolerance Time	Requirement
Routine	Firefighter operating hoses or fighting fire from a distance	60-100	0.83-1.67	10-30 min	No special clothing required
Hazardous	Situation outside a burning room or firefighter ventilating a fire without water	120-300	2-12.5	1-10 min	Turnout uniform is necessary to avoid burn injuries
Emergency	Situations encountered inside a burning building/room by firefighters	300-1200	12-200	5-20 s	Special thermal protective clothing required

And now if you want to classify the thermal environment, this can be classified in 3 different exposure. So, first is that it is a routine exposure, where the fire fighter operating hose or fighting fire from a distance ok.

So, when the operator is fighting fire from certain distance, but threat is not that much severe. The air temperature is not that high; 60 to 100 which is called routine exposure. The heat flux is from 0.83 to 1.67 **kW/m²** and we can have very high tolerance time and in this routine exposure we do not need any specific special clothing ok. But relatively hazardous exposure situation outside a burning room which it is not inside the room, outside the burning room or fire fighter ventilation, ventilating a fire without water.

So that in that case the air temperature is considered to be 120 to 300 **°C**. The heat flux is higher than earlier 2 to 12.5 and tolerance time is less where a fire fighter can stay there from 1 to 10 minutes and Turnout uniform is necessary to avoid any burn injury no special clothing is required. But some uniform is required. But in case of emergency situation that is situations encountered inside a burning building that type of situation is required by fire fighter.

The air temperature its ranging from 300 to 1200 **°C**, the heat flux is from 12 to 200 and the tolerance times will be from 5 to 20 seconds. So, in emergency situation, we need special thermal protective clothing. So, this thermal protective clothing is not normal so we have to have very special clothing.

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So, the type of burn injury is that the burn depth is measured depending on the severity.

The First-degree burn is the, that the skin becomes red, no blister formation and which will be actually a person will be recovered after few day; it will be recovered. And the Second-degree burn, the skin blister epidermis must regenerate. So, the epidermis will be regenerated and this can be recovered ok and in most of the cases, we can go up to this second-degree burn ok, we can predict and beyond the second degree burn which is called Third-degree burn, full thickness of the skin is destroyed and skin cannot be regenerated, scar formation is there.

So, that situation should not be actually is reached, before that we should be able to come out from the fire condition and the time required for the second-degree burn is extremely important and that is actually measured for by the different instruments. So, that is the measurement techniques.

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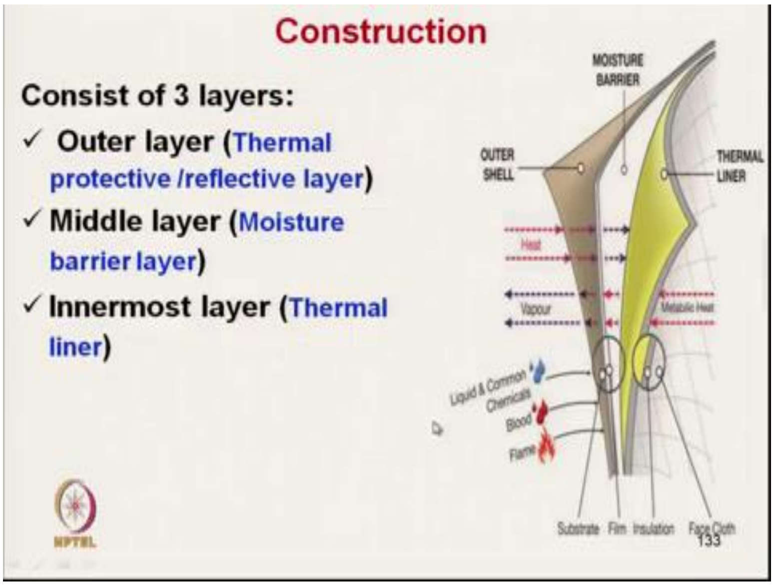

And the construction is that most of the fire fighter clothing, they have 3 layers. The Outer layer which is Thermal protective or reflective layer; this is outer layer. And Middle layer is Moisture barrier layer; that means, it will not allow the water molecule to come inside, but the moisture vapor it will allow the to pass through that. So, whatever the sweat whatever the moisture generated in the human body, it should actually get transmitted through this barrier. And Innermost layer which is Thermal liner which is actually which protects the fabric which it protects the human body from the heat exposure its mainly the insulating layer.

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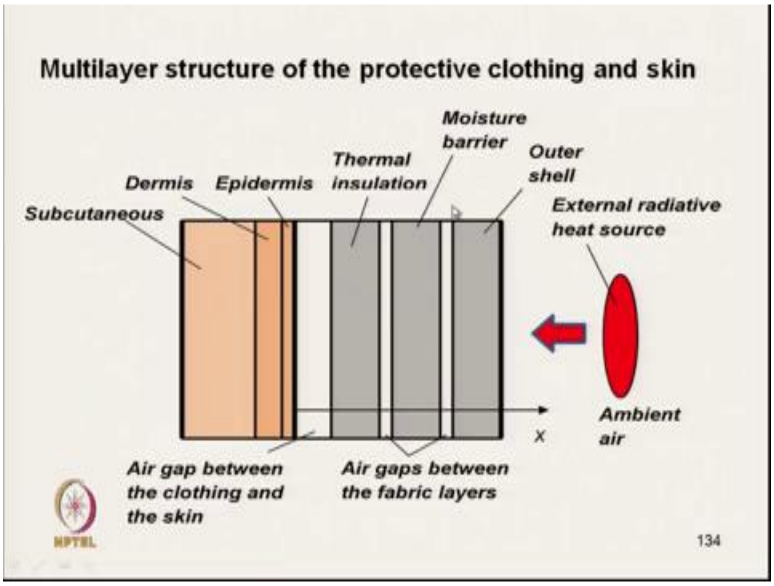

So, if you see with this schematic diagram the different layers so multilayer structure of protective clothing and skin, this red source it is a external radiative heat source. So, Ambient air where external radiative heat source, it may be any radiative heat source may be flame, maybe fire, any heat source and this grey part its showing the protective clothing.

So, protective clothing has got 3 layers. So, outer layer outer cell, moisture layer middle and thermal insulation and in between this layers the gap which is air gap is created which also helps in providing the insulation and this portion it is called the microclimate air gap between the clothing and the skin and the left portion, this is actually the human skin; Epidermis, Dermis and Subcutaneous tissues. So, from there we can predict the heat transmitted to the epidermis which will be actually which will result the second-degree burn and we can predict the second-degree burn time. So, there are different test methods for extreme heat protective clothing.

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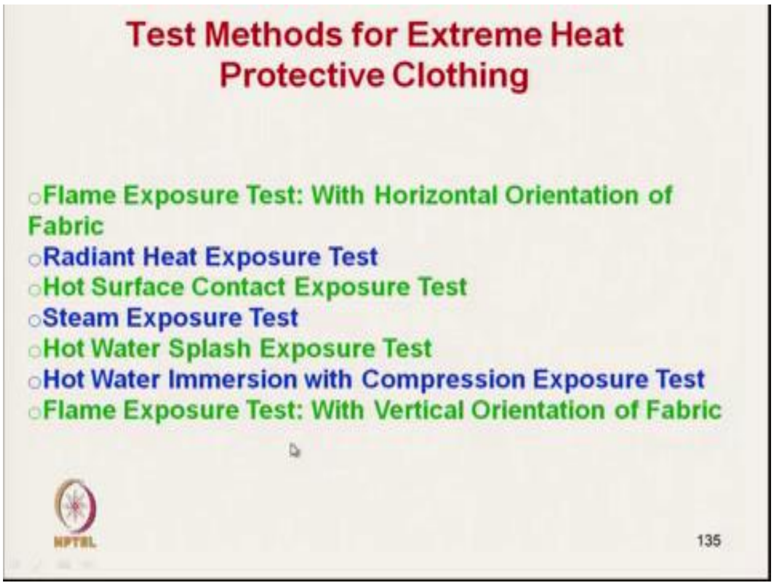

So, these test methods are first is that Flame Exposure Test; Flame exposure test are of two types. One is that With Horizontal Orientation of Fabric; another is Vertical Orientation of Fabric. So, flame exposure test with horizontal orientation of fabric; here the fabric is exposed with direct flame and the heat transmission and second degree burn time is recorded. Next is that radiant heat exposure test; here the heat source is that radiant heat. Earlier case it was the flame. In this case, the heat source is the radiant heat and the fabric is exposed to that radiant heat and the amount of heat which is transmitted through the fabric is measured. Next is called Hot Surface Contact Exposure Test.

The Radiant heat exposure test was not in contact. So, this is a fabric specimen clothing and the radiant heat there is the source which is not contact with the fabric. But in this Hot surface contact exposure test is that fabric is exposed with the hot surface. So, hot surface is in touch with the fabric and then, the amount of heat transmitted through the fabric is measured and the second degree burn time is calculated like this is my clothing and some hot surface is in touch with the fabric say hot iron is in touch. So, how long will you take to have second degree burn is measured using this type of test and radiant heat that means, the radiant heat source is in not in contact.

Next method is that Steam exposure test. So, after hot surface or radiant heat exposure, suppose this is the fabric. Now I am wearing this clothing, some steam is coming out sometime it happen. So, during the steam; so, I may get actually I am injured by the heat injury and this level of heat actually transmitted through the fabric due to the steam exposure is measured in this test.

Next method its Hot Water Splash Exposure Test. Now sometime it may happen; the fabric is there hot water is been splashed on the fabric and the level of protection the fabric will be given is tested by this method. Another method here it is a Hot Water Immersion with Compression Exposure Test.

Suppose the fabric the person is actually jumping inside a hot water. So, how will it actually transmit the heat from the hot water to the skin, this test method will measure. And last method as I have mentioned in the first method it is a first method it was the Flame Exposure With Horizontal Orientation and last method is a Flame Exposure Test With Vertical Orientation, where the fabric orientation is in vertical condition because in most of the application we have seen the fabrics are in vertical condition.

So, in this test we can measure the flame exposure, the heat transmission through fabric in vertical orientation condition. So, all these test method the unique purpose of this methods just to measure the heat transmission through the fabric and to predict the second degree burn condition and in all these process, all these methods the heat is being supplied in one direction, one side of the fabric, one surface of the fabric and from other surface of the fabric, we actually record the heat transmitted.

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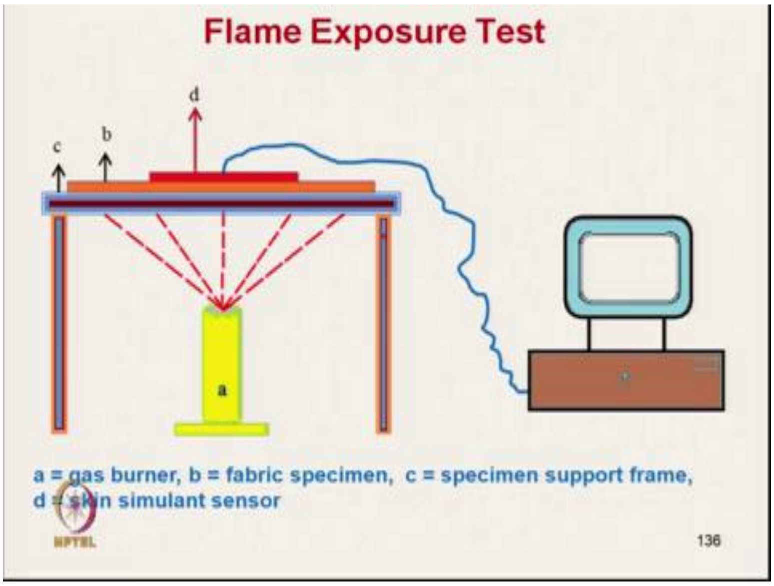

The first which is called Flame Exposure Test, here the components are a its a gas burner which actually produce flame and c is the specimen support frame and the fabric b is actually fixed on specimen support frame and other side of the fabric, fabric is actually exposed to the flame from the bottom and fabric is placed in horizontal condition and on other side of fabric, there is the skin simulant sensor.

There is a sensor heat sensor which is actually representing the human skin. Now once the flame is exposed to the fabric is exposed to the flame, the heat will be transmitted through the fabric and the skin simulant sensor will sense the, will measure the heat and it will actually measure the time required for second degree burn.

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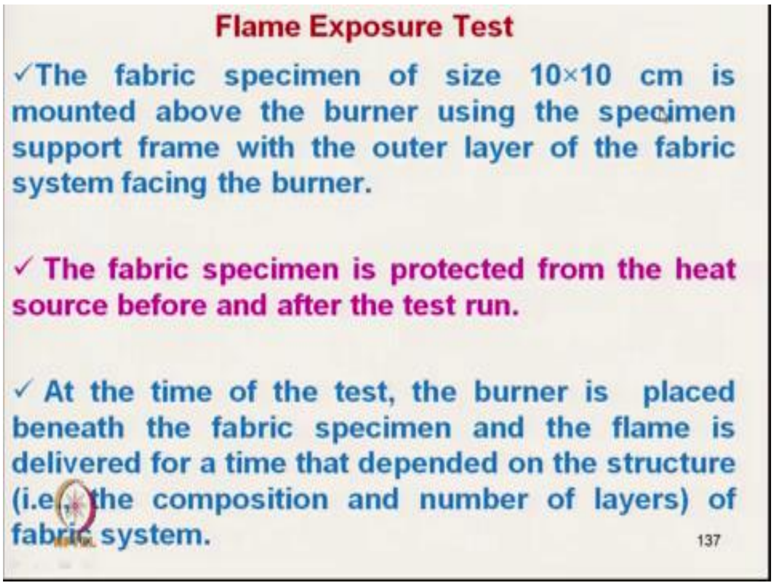

The fabric specimen of size 10 by 10 cm, the 10 cm by 10 cm square fabric is mounted; mounted above the burner using the specimen support frame with the outer layer of the fabric system facing the burner ok. So, one layer is facing the burner, the fabric specimen is protected from the heat source before and after test run. So, before and after test run, the fabric specimen is protected with some shutter arrangement. At the time of the test the burner is placed beneath the fabric specimen and the flame is delivered for a time that depends on the structure of the fabric.

Now if the structure of the fabric is thicker, if it is thicker fabric or very compact fabric; then, flame exposure time will be high. So, depending on the structure of the fabric, the flame exposure time is changed and level of flame or is also changed.

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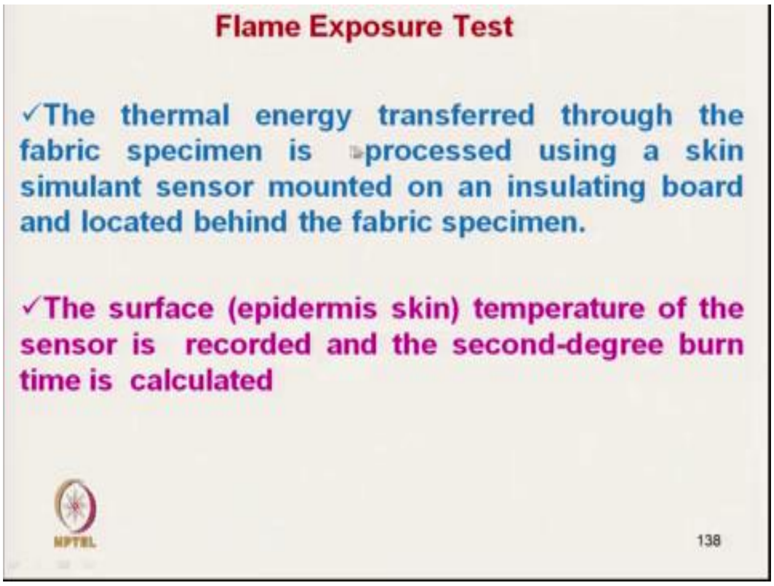

The thermal energy transferred through the fabric specimen is processed using a skin simulant sensor mounted on an insulating board ok. So, on an insulating board a skin simulant is mounted and which is located just behind the fabric specimen. In one side the flame exposure is there and in other side it is a skin simulant is placed.

The surface that is a epidermis of the skin that the simulate surface, the surface temperature of the sensor is recorded and the second degree burn time is calculated. So, that skin simulate it records the surface temperature and the time required to reach the second degree burn time temperature second degree burn temperature that whatever time its reached that is calculated and it gives the thermal insulation of the fabric in terms of the second degree burn time.

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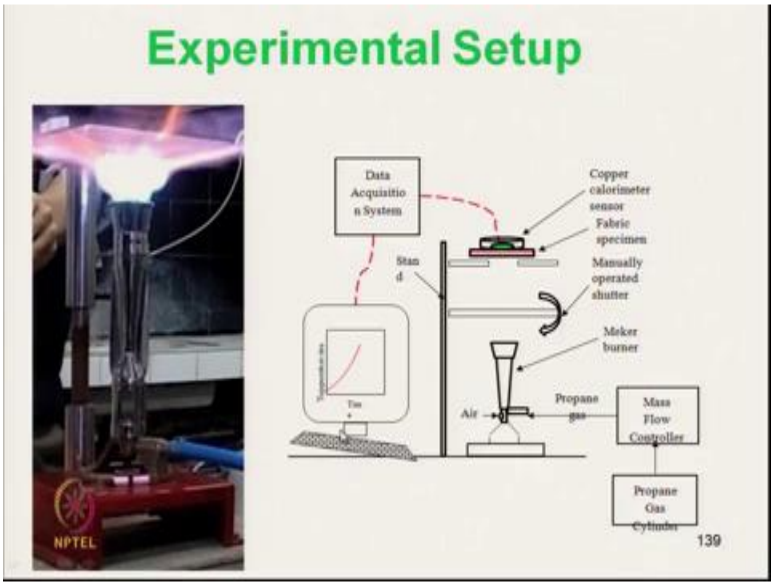

The next method is that the same method which we have developed in our laboratory here which is the Experimental Setup which is the direct flame exposure using horizontal fabric alignment from the bottom of the fabric specimen, the flame is exposed as the fabric is exposed through the flame and on other side it is the skin simulant is there the heat sensor and the computer records the temperature increase the level of temperature increase with the time.

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This is the Experimental Setup. Here, the gas open gas we normally use here and which is with the controller which controls the level of flame and there is a shutter after the removal of shutter, we record the time and the computer records the level of heat exposure heat transmission and the increase in temperature.

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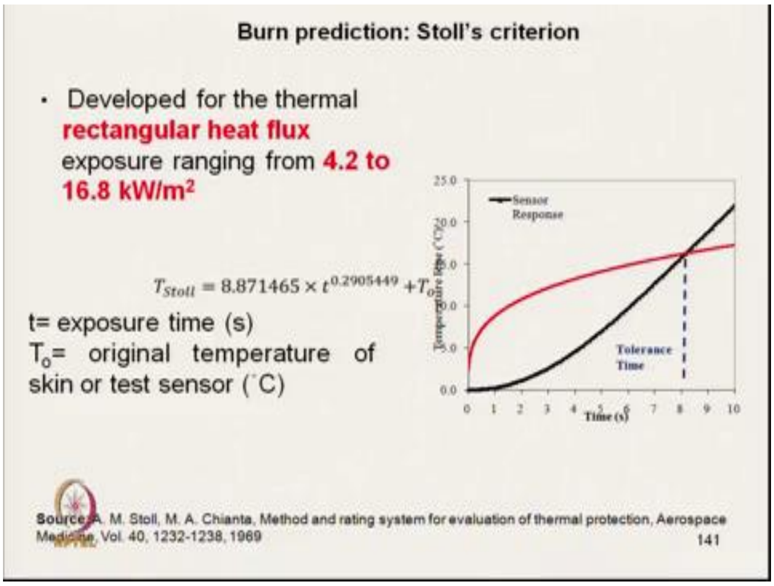

And we use the Stoll's curve to predict the second degree burn time. So, this is the response and Stoll's response curve. Its shown in the red color and the sensor response is in black color and at this point when its intersecting this point which is as per this picture it is a 8 second. This means thus at 8 second, it reaches the second degree burn. So that means, the fabric assembly will have the second degree burn after 8 second.

Just to compare the burn prediction with the Stoll's criteria.

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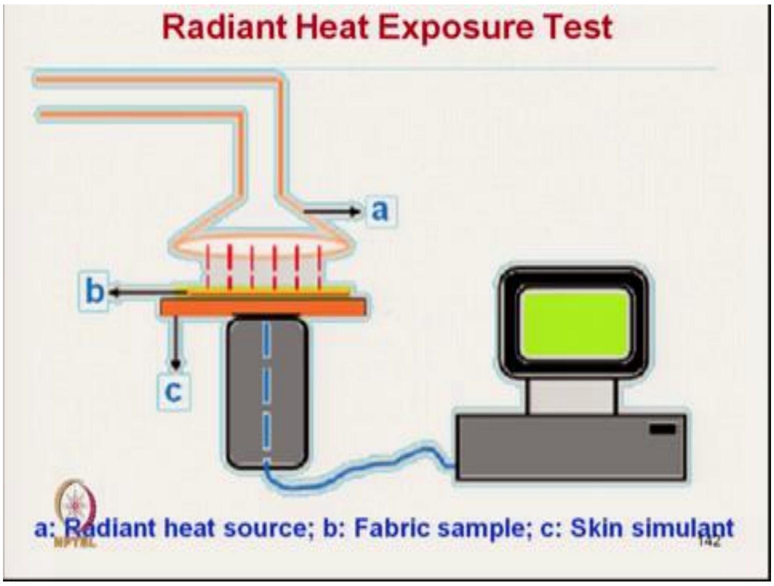

Next technique which is Radiant Heat Exposure Test; here the fabric specimen which is b placed in horizontal direction; a is the source of radiant heat, here it is a lamp radiant heat lamp is there heat source and c other side it is a skin simulant. So, from top the heat is exposed, then the fabric is placed; the radiant heat passes through the fabric and on other side skin simulant is kept and like earlier case here also skin simulant will receive the heat from the radiant source which is actually transmitting through the fabric and the data is recorded and processed using special software.

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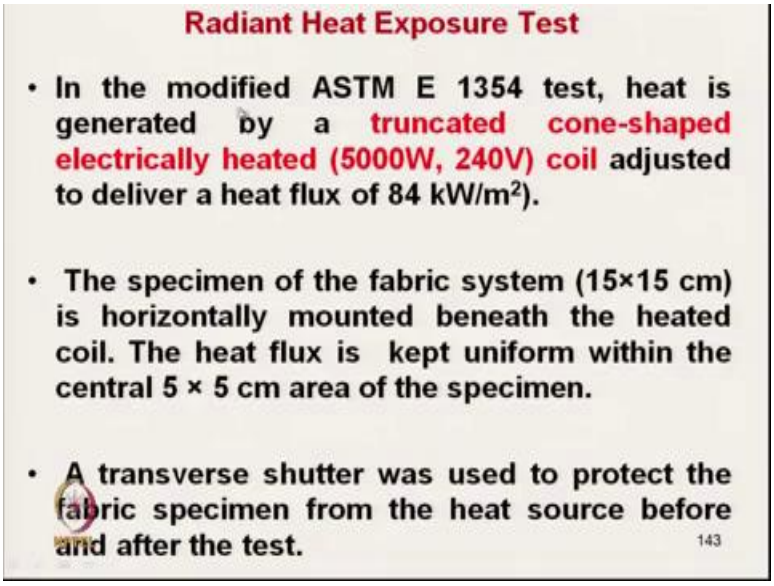

In the modified ASTM E 1354 test, heat is generated by the truncated cone-shaped electrically heated coil adjusted to deliver a heat flux of 84 **kW/m²** that is the amount of heat which is required for second degree burn and the heater is 5 **kW** watt 240 V ok. The specimen of the fabric system that is 15 by 15 cm which is placed horizontally mounted beneath the heated coil. It is placed just below the heated coil and the heat flux is kept uniform within the center that is 5 centimeter by 5 centimeter area of the specimen.

So, total area of the specimen is 15 cm by 15 cm and at center at least with 5 centimeter by 5 centimeter area, the heat flux should be kept uniform ok. So, that uniform that and below that area, the skin simulant is placed. A transverse shutter was used to protect the fabric specimen from the heat source before and after test; that means, the heat source the light electrically heated coil, it is actually it starts releasing heat. But the shutter is placed when we need to measure when we start recording the time that time we remove the shutter.

And after the test to protect the fabric, we close the shutter so that the extreme heat does not transmit through the fabric.

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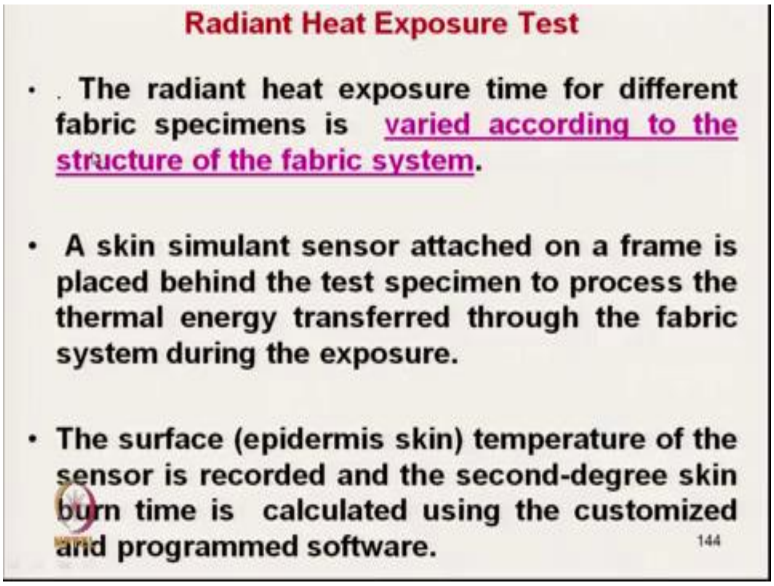

The radiant heat exposure time for different fabric specimens is varied according to the structure of the fabric. So, radiant heat exposure time will be high for thick fabric and vice versa. For thin fabric we can expose with the shorter time. A skin simulant sensor attached on the frame is placed behind the test specimen, just below the test specimen to process thermal energy transferred through the fabric during the exposure.

So, it records the thermal energy which is transmitted through the fabric and this surface of this skin simulant which simulates the epidermis of the skin, the surface temperature of the sensor is recorded and the second degree skin burn time is calculated using customized and programmed software. So, this customized software's was also used for flame. Here also for radiant heat exposure, we can use some customized programmed software. So, will stop here we will continue with the measurement of heat transmission in extreme heat condition in next class.

Till then thank you.