Technical Textiles
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Lecture - 22
Extreme Heat Protective Clothing

Hello everyone. So our today's topic is the fire protective clothing, extreme heat and fire protective clothing. So the heat may be due to fire or maybe due to any other source like any radiative heat. So here we will understand what type of protective clothing we must use. What are their constructions, different layers and what are the different types of materials available at present and also we will try to see different standards available and different measurement techniques of heat and fire protective clothing.

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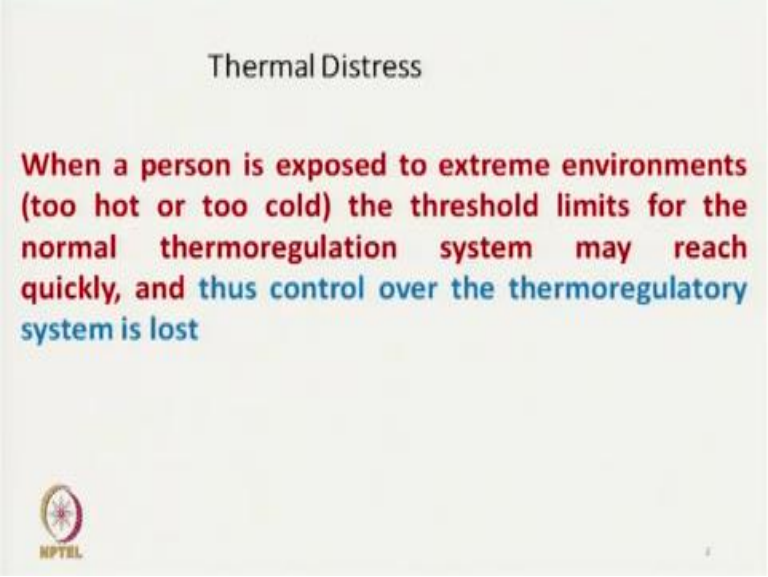

So, thermal distress as has already been mentioned is of two types due to extreme cold and due to extreme heat. At present topic we will discuss the thermal distress due to extreme heat. So when a person is exposed to an extreme environment, extreme hot or extreme cold, the threshold limits for the normal thermoregulation system, it reaches quickly. So our body thermoregulatory system does not work.

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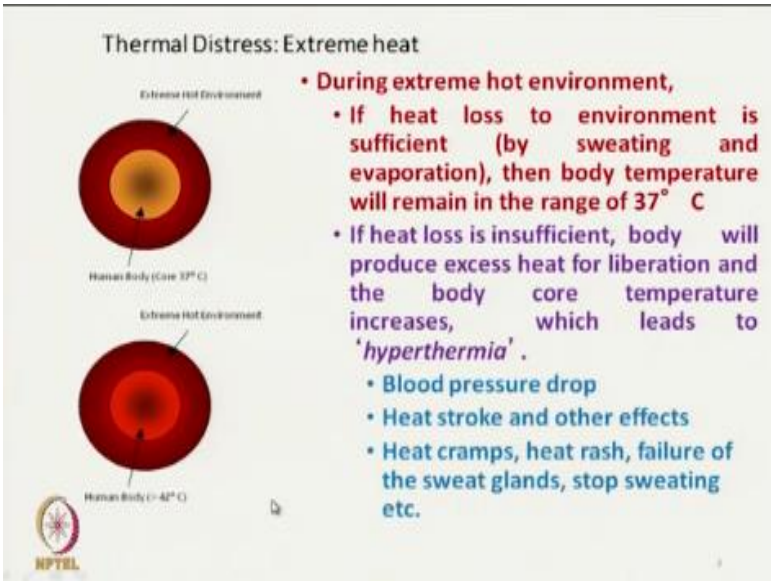

So this picture shows the body core temperature, which is 37 degrees, which is actually normal. The environmental temperature is hot but to keep our body temperature under control we must wear proper thermal protective clothing. So during extreme heat environments, if the heat loss to the environment is sufficient, that is by sweating and evaporation, then the body will maintain the temperature at 37 degree Celsius.

This can be done by preventing the heat from entering our body and at the same time whatever heat our body is generating, we must allow this heat to come out from the body. With extreme heat conditions when the outer environment is warmer than our body. So we will start receiving the heat by conduction and radiation because conduction and radiation takes place based on the temperature gradient, heat will try to flow from higher temperature to lower temperature, which is our body.

But the two ways to protect or maintain our body core temperature at around 37 degree Celsius is either by proper evaporation of sweat and also by preventing this conductive and radiative heat coming from the environment to our body and this can be done by proper selection of the heat protective clothing. If we cannot do so our body core temperature will increase and with the increase in body core temperature will reach a condition which is known as hyperthermia.

Where body heat loss is insufficient and body will start receiving heat from environment. So during that drop in blood pressure takes place, heat stroke and other effects will occur, heat cramps, heat rash, failure of sweat glands, which is dangerous because sweating is a process by which our body releases it and also by evaporation of sweat body releases extra heat off that is latent heat.

So we must create a situation where the excess heat does not enter our body, we must protect ourselves from extreme heat.

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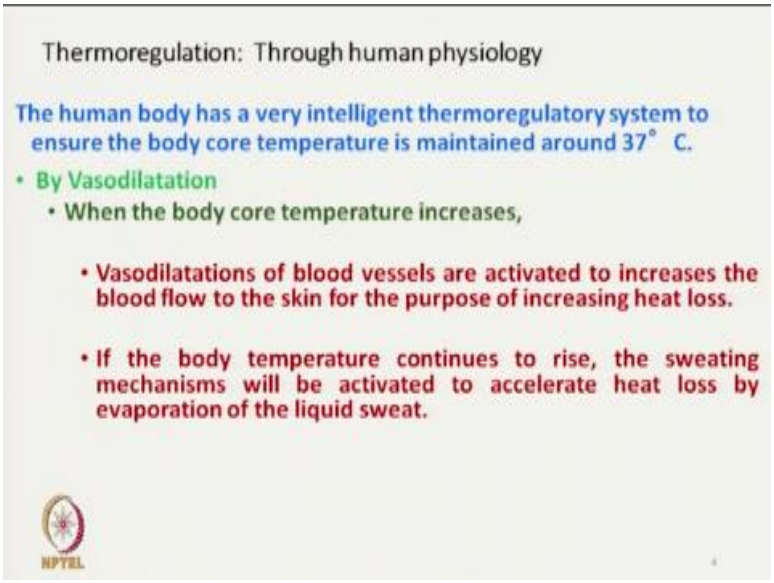

So we try to maintain our body temperature at around 37 degrees Celsius through our thermoregulatory system by vasodilation, when the body core temperature increases through vasodilation the blood flow rate increases and we increase some heat. So these are the different phenomena that would happen as I have already mentioned if the body temperature continues to rise the sweating mechanism will be activated to accelerate heat loss and through evaporation of sweat we release some more heat.

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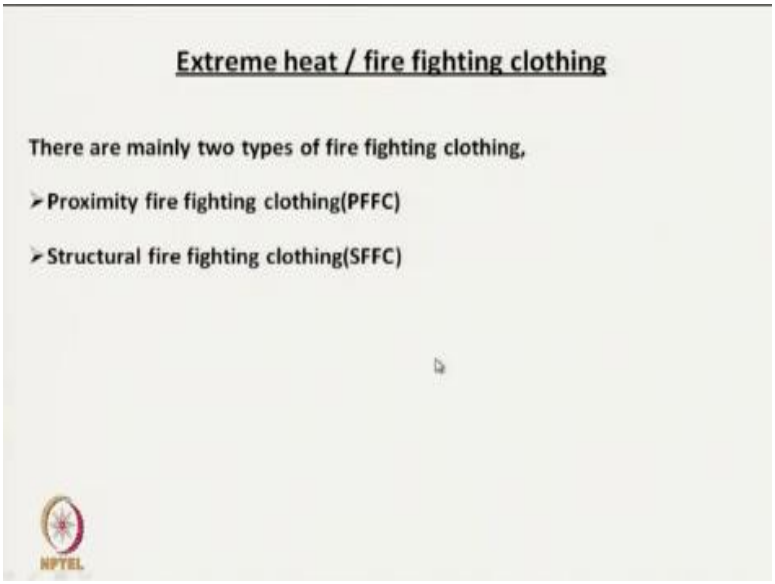

Now coming to the type of fire fighting clothing, extreme heat protective clothing, they are basically divided in two broad categories. One is proximity fire fighting clothing PFFC, another is structural fire fighting clothing. The proximity fire fight clothing is those clothing where the fire fighter, going close to the fire, is not entering to the fire and the fire mainly the radiative heat penetrates to the human body and to prevent that radiative heat we may use reflective coating.

Another fire fighting clothing is that structural firefighting clothing SFFC, where a person can enter into the fire to protect human life or may be property where the threat is much more than proximity fire fighting clothing.

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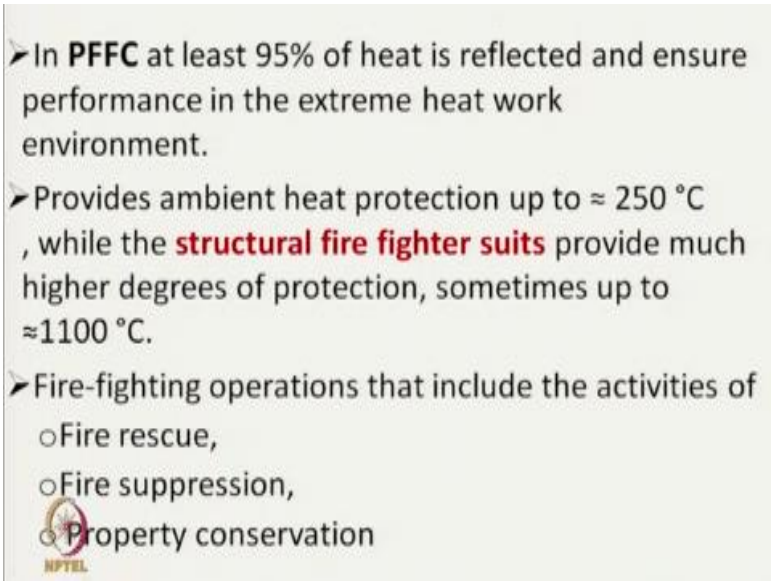

In proximity fire fighting clothing at least 95 % of heat is reflected and ensure performance of extreme heat work environment. So we have to ensure that the majority of the heat is reflected out and provides ambient heat protection up to 250 degree Celsius, but on the other hand structural fire fighting suit is designed to protect human beings to much higher temperatures that is around 1100 degree Celsius.

So fire fighting operations include the activities of fire rescue, fire suppression, property conservation, there are many other applications. So this structural fire fighting suit is useful.

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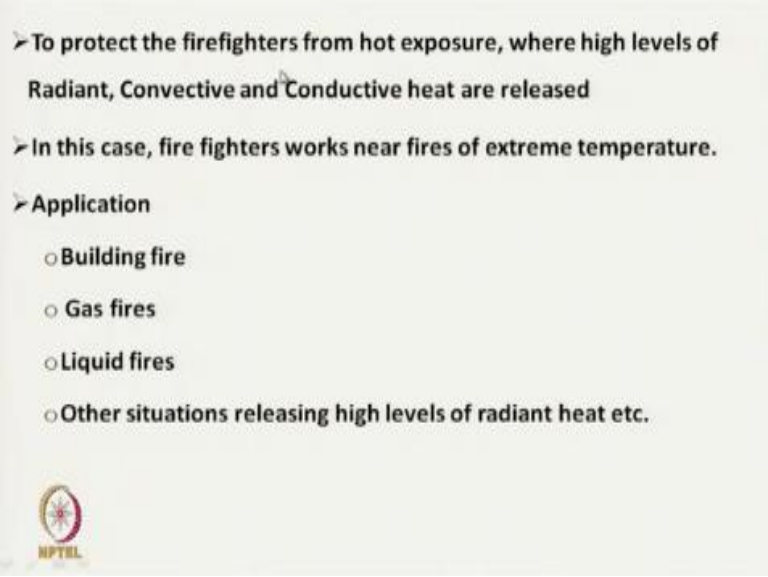

To protect the firefighters from hot exposure where high levels of radiant, convective and conductive heat are released. So in structural firefighting mainly radiant, convective, conductive heats are there. In this case, proximity fire fighting clothing, the firefighters work near fires of extreme temperature. So they do not enter into the fire, so this firefighter clothing application building fire, gas fire, liquid fire, other situations releasing the high level of radiant heat.

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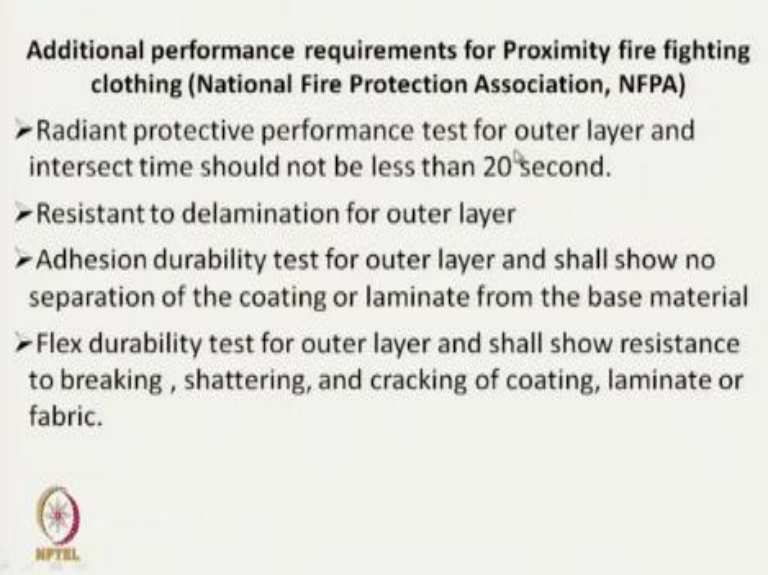

There are some additional requirements for proximity firefighting clothing as per national fire protection association NFPA, that radiant protective performance test for outer layer and intersect time should not be less than 20 seconds. So that majority of the heat comes through the radiative heat, so that performance should not be less than 20 second. Resistant to delamination of outer layer, adhesion durability test for outer layer and shall show no separation of coating or laminates.

So in this type of fabric that proximity firefighter clothing we need to have some coating, reflective coating but during use this coating should not be removed proper adhesion should be there, that is one of the important requirements. Also during flex movement that is flex durability test has to be there for the outer layer and shall show resistance to breakage, shatter or crack formation in coating or lamination.

So during the bending or flexing the outer layer crack formations should not be there. So, these are the additional requirements for proximity fire fighter clothing.

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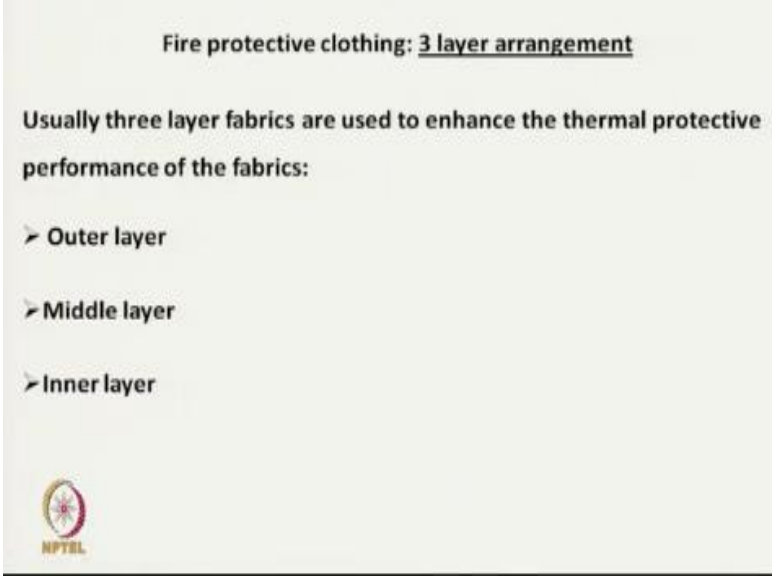

So if you see like extreme cold protective clothing, fire protective clothing also has three distinct layers, that is outer layer, middle layer and inner layer. Now we will discuss the construction and importance of three layers.

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This is the picture of a fire fighting clothing, where this is outer shell, thermal liner, and inner shell and at the middle it is a moisture barrier. So moisture barrier's function is to allow the moisture generated during activity in our body to come out from the inner layer to the outer environment to keep our body dry at the same time it should prevent any liquid, hot water or any sorts of liquid to penetrating inside.

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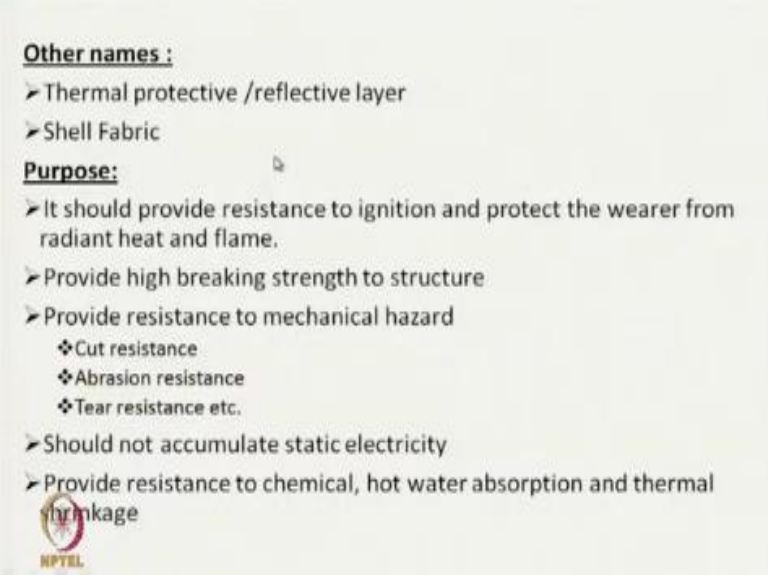

First let us discuss about the outer layer. So the other terms for outer layer are thermal protective layer or reflective layer or shell layer, we can call them different terms. Reflective layer is used where we use the reflective coating mainly for the proximity firefighting clothing. The purpose of the outer layer is that it should provide resistance to ignition. So once it is coming to extreme heat that the outer layer is the layer which is exposed to extreme heat or fire.

That means this particular layer should be fire resistant, it should not ignite easily and it should protect the wearer from radiant heat and flame. So it should not ignite and at the same time it should be heat protective as it is at the outer layer, so it is breaking strength should be high because it is keeping the total structure intact, it should be resistant to mechanical hazard like it should be cut resistant, abrasion resistant, tear resistant.

Because this outer is the layer which directly comes under different mechanical hazard, middle and inner layers are protected and protected by this outer layer. So the outer layer has multiple functions and also it should not accumulate static electricity. There are different situations, maybe abrasions, maybe other differences it can come close to some high electric field. So it should not accumulate static electricity.

At the same time it should provide resistance to chemicals, hot water, absorption and thermal shrinkage. This is the layer which comes directly under extreme heat and that is why the chances

of shrinkage of the outer layer is maximum, so it should be shrink proof. So we must select the material for the outer layer keeping all these requirements in mind.

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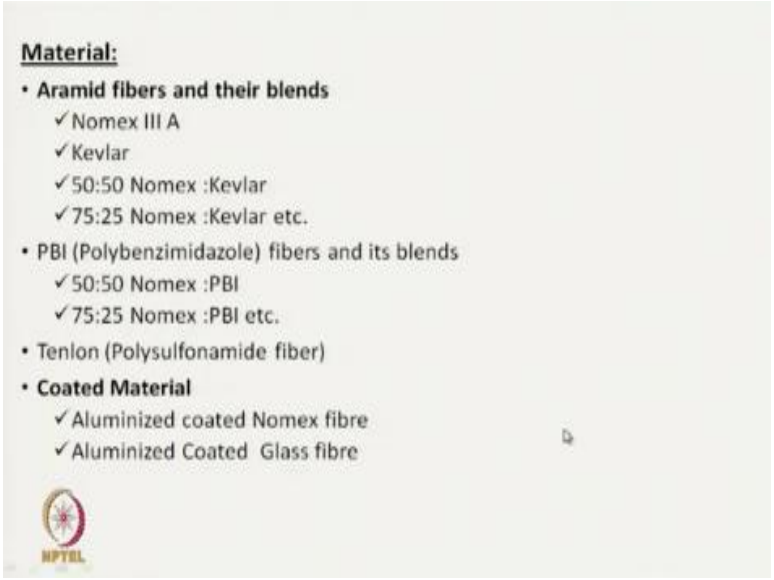

The materials which are used for outer layer fabric, Nomex III A, Kevlar, Nomex Kevlar blended material 50:50 or at different proportions it can be blended, the reason for blending I will discuss. PBI fiber and their blend, Nomex PBI, Nomex PBI of different combinations, sometimes tenlon fibers are used. If we want to have coating we can use aluminized coated nomex fiber or aluminized coated glass fiber.

So these are the materials which are suitable for outer layer fabric. Now coming to the middle layer, the middle means it is a moisture barrier layer.

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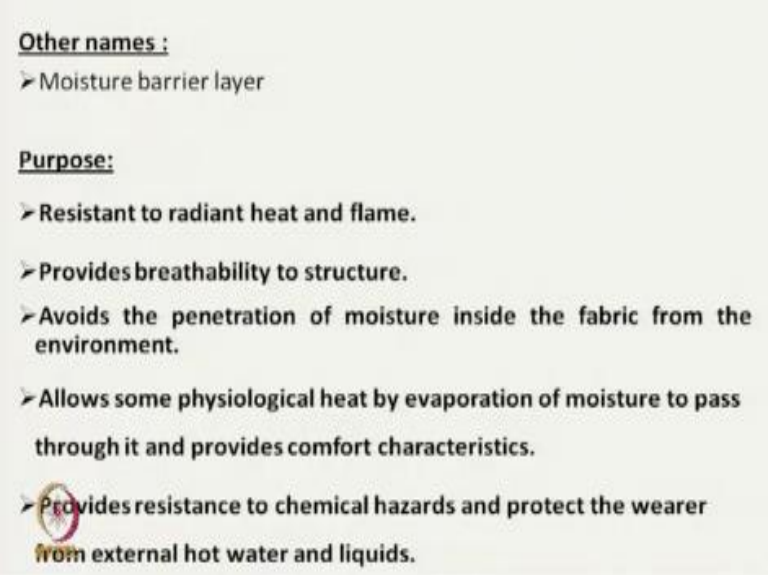

The other term is moisture barrier layer; the main function is to allow the moisture vapor form but it will not allow the water to come inside. So the main purpose here is through its resistance to radiant heat and flame, provides visibility to the structure. So it should have pores, it should avoid penetration of moisture inside the fabric from the environment, so in the form of liquid it should not penetrate inside the structure allowing some physiological heat by evaporation of moisture to pass.

So, whatever evaporative physiological heat we produce it normally should allow, it to evaporate in the form of moisture and provide comfort to the wearer, the layer should provide resistance to chemical hazard and protect the wearer from external hot water and liquid. In case of splashing of hot water or liquid, this layer should prevent the hot water or any other liquid or chemical to penetrate inside.

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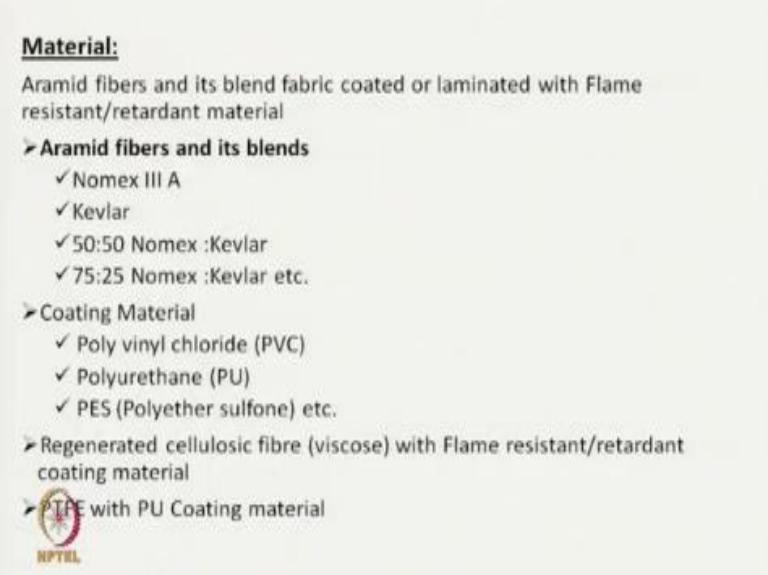

The materials which are being used here are aramid fibers and their blends or laminated with flame resistant or flame retardant material. So aramid fibers or their blends are similar to the outer layer also. Here along with the fabric the coating is needed to keep it breathable, we need to apply breathable coating at the same time it should be waterproof, waterproof breathable coating should be there.

So these materials, the coating materials are PVC, polyurethane or PES, polyether sulfone. These are the coating materials, sometimes regenerated viscose fibers are also used but flame retardant viscose fibers are used PTFE with polyurethane coating materials, these are the materials. So here we should use one coated fabric and the inner layer.

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Which is actually thermal insulating layer, that is why this layers' other name are;

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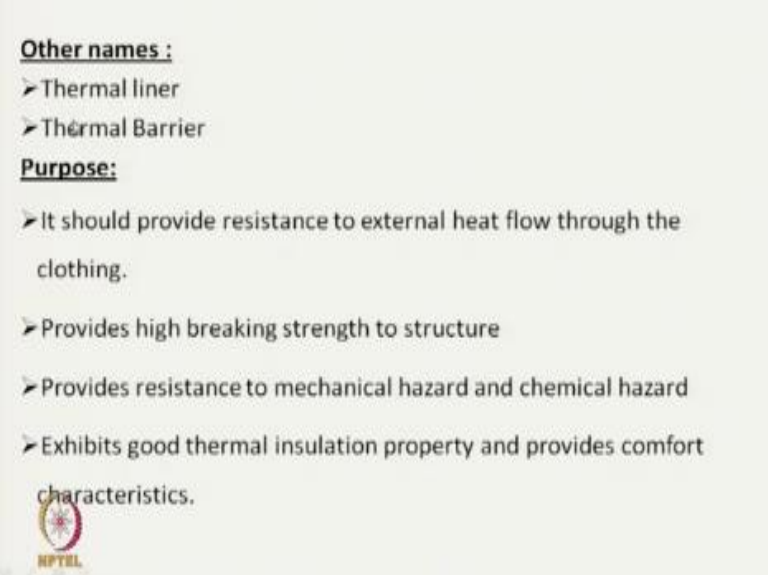

Thermal liner or thermal barrier, the main purpose is that it should provide resistance to external heat, so resistance to external heat flow through the clothing. So from outside the heat should not be transmitted through this clothing it provides thermal resistance, provides high breaking strength to the structure, provides resistance to mechanical hazard and chemical hazard, exhibits good thermal insulation property and provides comfort characteristics.

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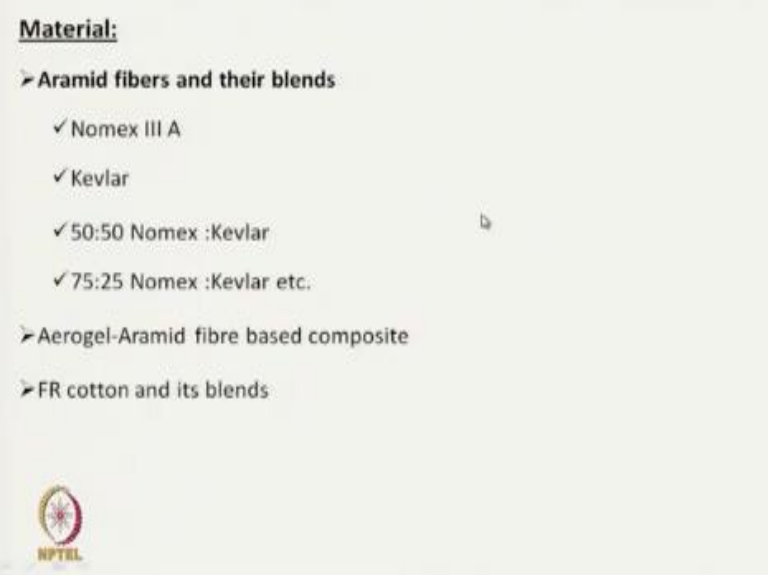

So materials, the similar materials are used like aramid fibers, Nomex and their blends, Kevlar, Nomex Kevlar blends and sometimes we use aerogel based aramid composite. So aramid fibers with aerogel composites are used and at the inner layer or fire retardant cotton and the blends are also used as the inner layer.

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Possible layers in ensemble

	Outer layer	Thermal liner	Inner layer
1	Aluminised coated Nomex woven Fabric	Aerogel based Composite with nonwoven fabric	Modacrylic/Cotton (Woven cloth)
2	Aluminised Coated Glass woven Fabric	Nomex(Needle Punched)	Wool/ Viscose (Woven cloth)
3	Nomex III A woven	Aerogel based Composite with nonwoven fabric	Modacrylic/Cotton (Woven cloth)
4	Nomex III A woven	Nomex(Needle Punched)	FR cotton (Woven cloth)
5	Glass woven fabric	Nomex(Needle Punched)	Modacrylic/Cotton (Woven cloth)
6	Blended PBI woven Fabric	Nomex (Needle Punched)	Wool/ Viscose (Woven cloth)

The possible layers are shown in this table, the outer layer, inner layer, here thermal liner is used. So at the middle layer what I have seen we have discussed here, the middle layer is the moisture barrier layer, the moisture barrier layer is not required for structural firefighter clothing. Moisture barrier is required for proximity firefighter clothing, because proximity firefighter clothing the

fire fighter works for longer time where moisture whatever it is generated inside the body, it should come out with the time.

But structural firefighter clothing is basically required for a short span of time. So there are different combinations one can try.

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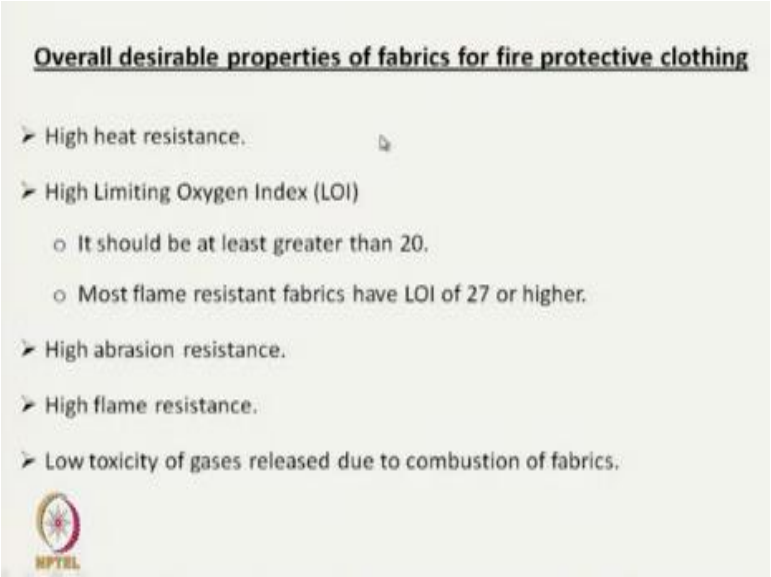

So overall desirable properties of fabrics for fire protective clothing is high heat resistant, high LOI value, it should be at least greater than 20, most flame retardant fabrics have LOI of more than 27, high abrasion resistance, high flame resistance, low toxicity of gases released due to combustion of fabrics, that is very important in selecting the coating material and fiber material. Due to high heat or flame the material should not release toxic gas. That is the reason for some death occurring due to release of toxic gas not due to heat.

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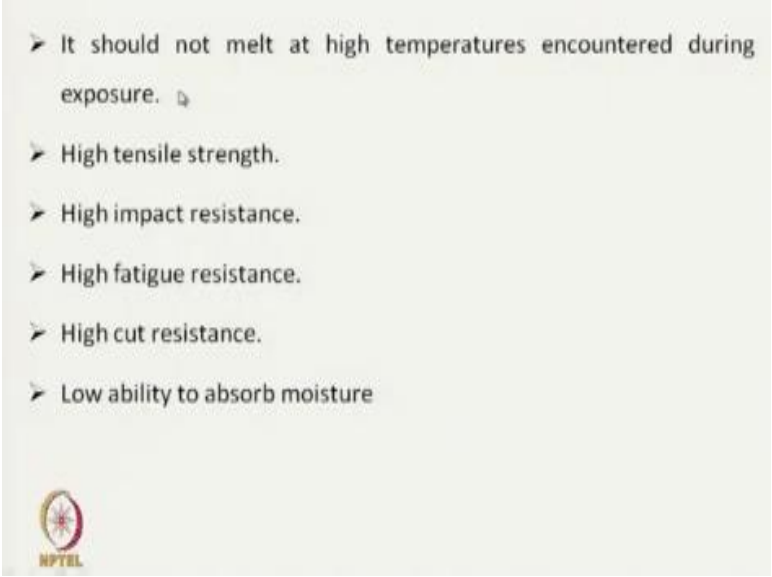

The material should not melt at high temperature; high tensile strength should be there at least at higher temperature, higher impact resistant, high fatigue resistance, high cut resistance, low ability to absorb moisture. So it should not absorb moisture to a higher extent. Now coming to the importance of:

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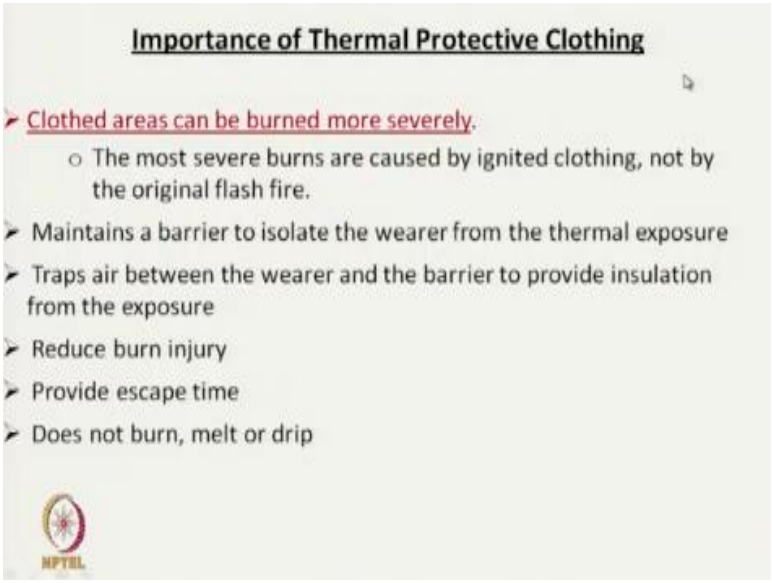

Thermal protective clothing. It has been observed that clothed areas can burn more severely than the unclothed portion. So the most severe burns are caused by ignition of clothing not by the original flash fire, because the original flash fire is for a fraction of time a few seconds, but once the cloth starts burning, it ignites that will create severe burning. So this protective clothing

should maintain a barrier to isolate the wearer from thermal exposure; it should trap air between the wearer and the barrier to provide insulation from exposure.

So we should design clothing looking at all these points, it should reduce the burn injury, it should be able to provide sufficient escape time and does not burn melt or drip. These are the important requirements, important considerations we should make before selecting the clothing material. In addition to the protective clothing,

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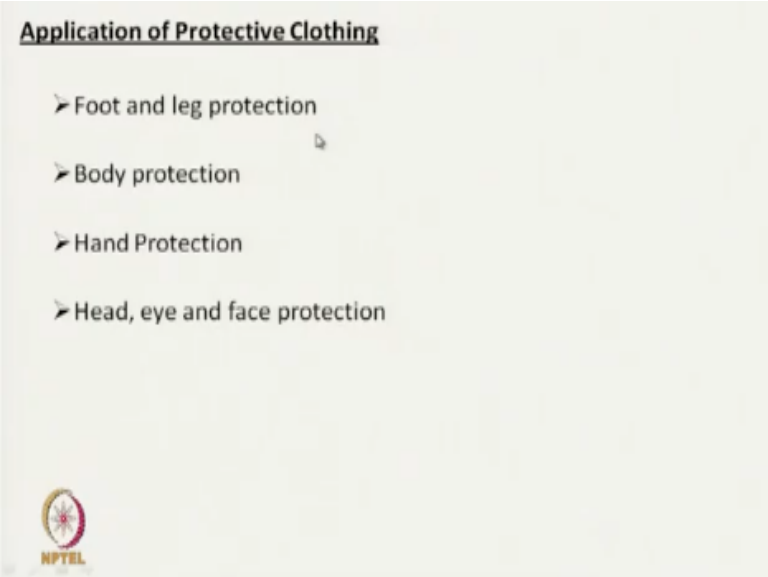

Foot and leg protection should be there, hand protection should be there, head, eye, face protection should be there.

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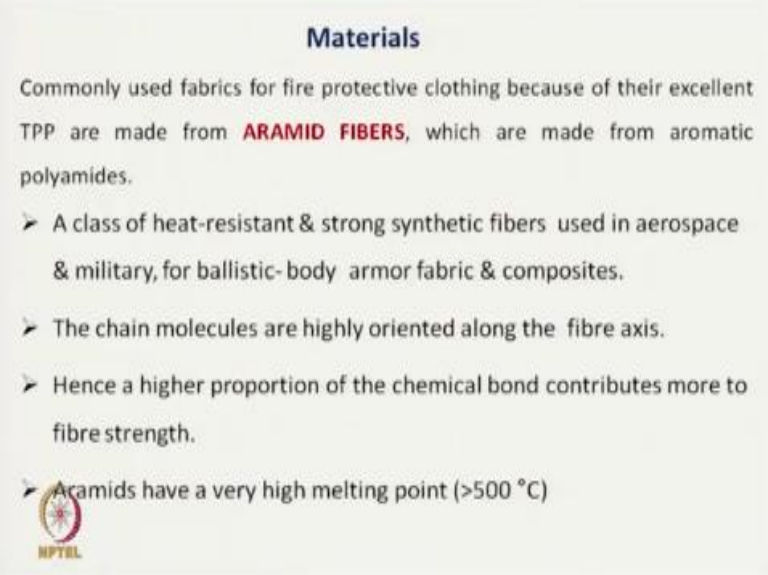

So there are different materials which are available to provide all these requirements that have been discussed. So the most common material is aramid fiber used for fire protective clothing, these aramid fibers are made from aromatic polyamines. These aramid fibers are two types; meta-aramid and para-aramid. So these aramid fibers are class of heat resistant strong synthetic fibre used in high activity use high end use like aerospace military application, ballistic application.

The chain molecules are highly oriented along the axis hence their strength is very high there and their melting point is very high it is more than 500 degree Celsius.

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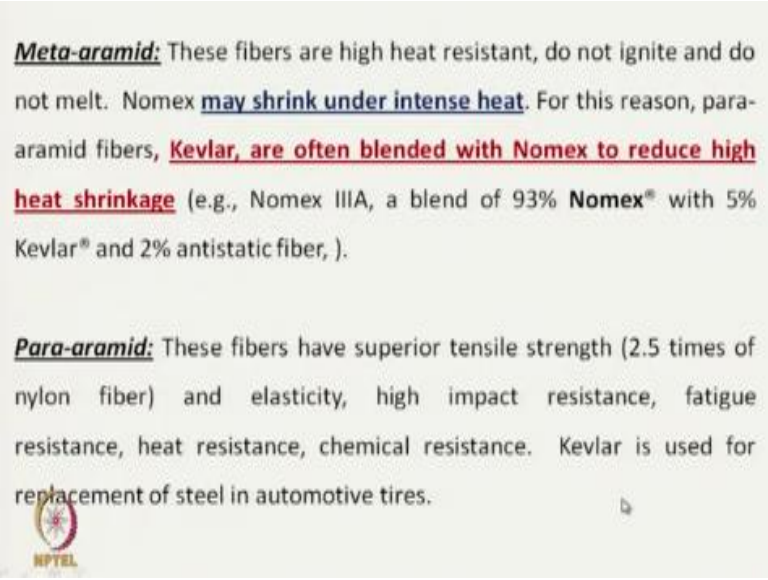

So meta-aramid is that they are high heat resistant fiber, they do not ignite and do not melt. These are the requirements of fire protective clothing that is why meta-aramid is widely used in fire protective clothing production; Nomex is fiber from du Point**.** So this fiber sometimes may shrink under intense heat, for this reason para-aramid fibers are mixed with the meta-aramid fiber.

So Kevlar when mixed with the meta-aramid fiber like Nomex, we can get Nomex III A which is a blend of 93% Nomex with 5% Kevlar and 2% antistatic fiber. Nomex III A is one fiber which is blended fiber, para-aramid fibers have superior tensile strength and elasticity, high impact resistance. So for this reason they are used with high strength applications, like automotive tires or ballistic applications.

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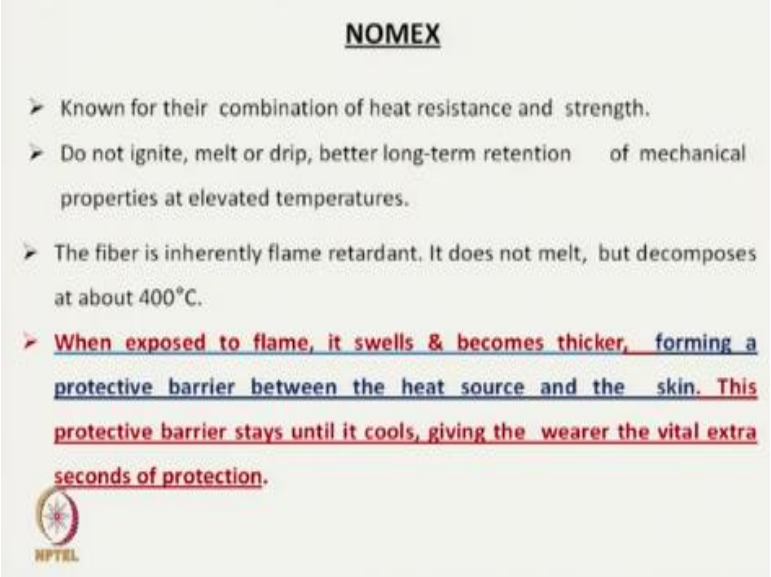

The Nomex is known for their combination of heat resistance and strength. They are both highly strong and heat resistant; they do not ignite melt or drip better long term retention of mechanical properties at higher temperature, so they are inherently fire retardant. They do not decompose at high temperatures around 400 degree Celsius. Another advantage of Nomex fiber is that once this fiber is exposed to flame or high heat this fiber swells that means the diameter increases they become thicker and which makes the fabric out of that fiber compact.

So they form a protective barrier between heat source and the skin due to compact structure once the fabric cools down the diameter becomes again normal, it reduces and during this swelling they give extra protection to the wearer. This is one interesting characteristic of Nomex that is why Nomex is used for the outer layer.

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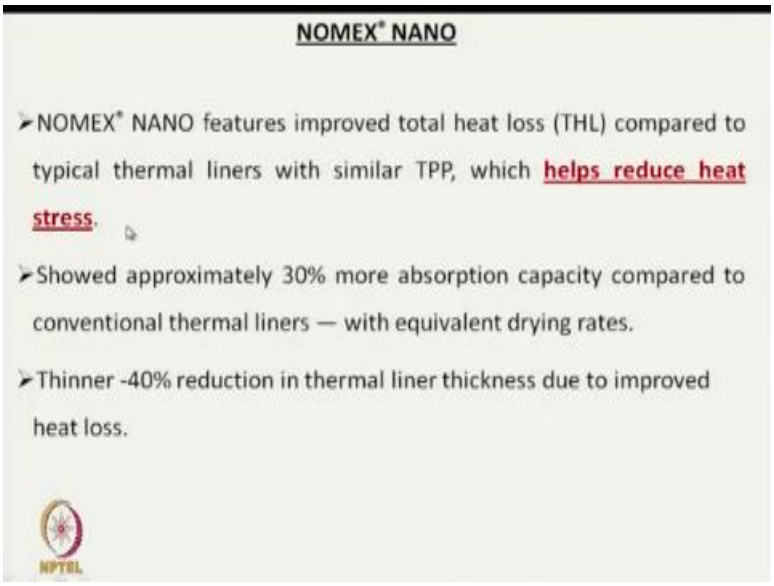

Another fiber, which is Nomex Nano, features improved total heat loss compared to normal typical thermal liner. So which reduces the heat stress, it shows approximately 30% more absorption capacity compared to conventional thermal liners.

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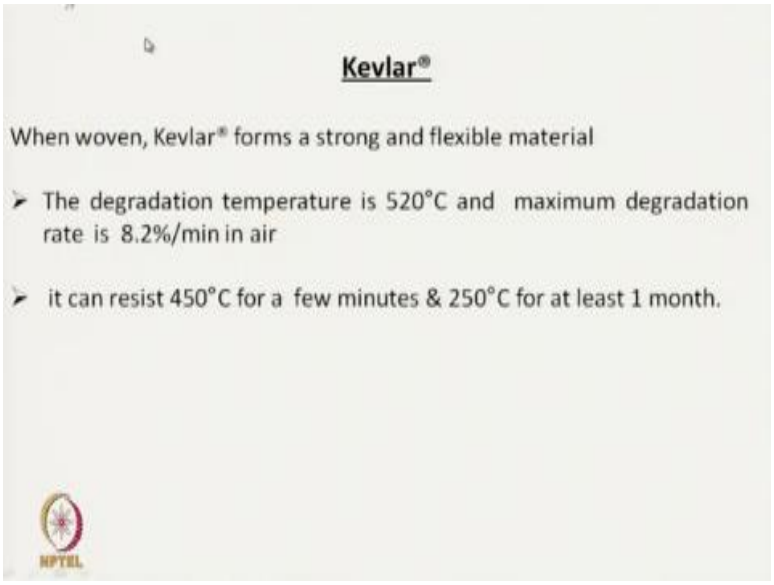

Kevlar is also used so the woven Kevlar fabric is very strong and flexible also as per as degradation is concerned, the degradation temperature is 520 degree Celsius and maximum degradation rate is 8.2% per millimeter in air. So it can resist 450 degree Celsius for a few minutes and at 250 degree Celsius at that high temperature for at least one month it can retain its strength. So at high temperature conditions this fiber is useful. The next material is M5 fiber.

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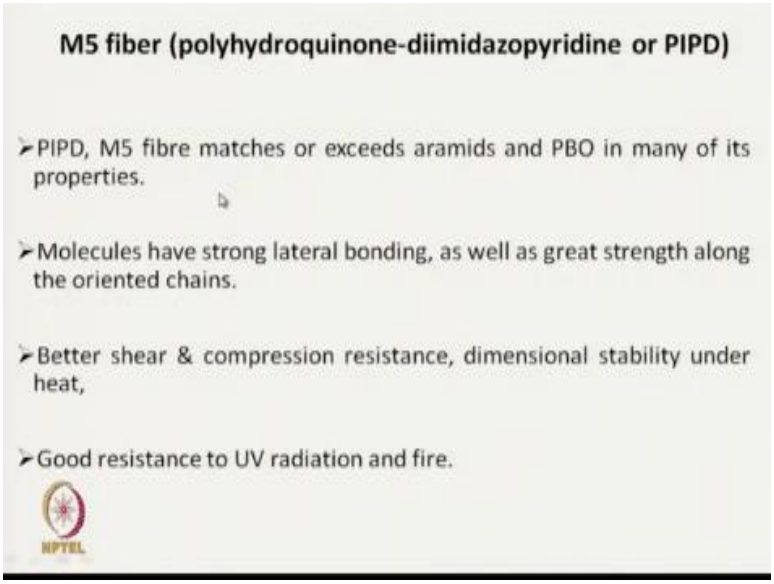

It actually matches or exceeds the aramids and PBO fiber as per as their properties are concerned molecules have strong lateral bonding. So they are very strong, better shear and compression resistant.

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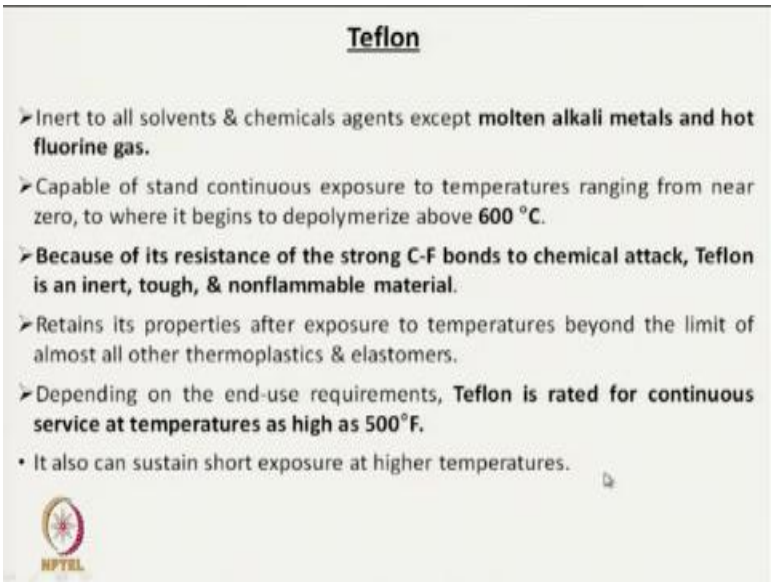

Teflon is another material which is used for fire protective applications.

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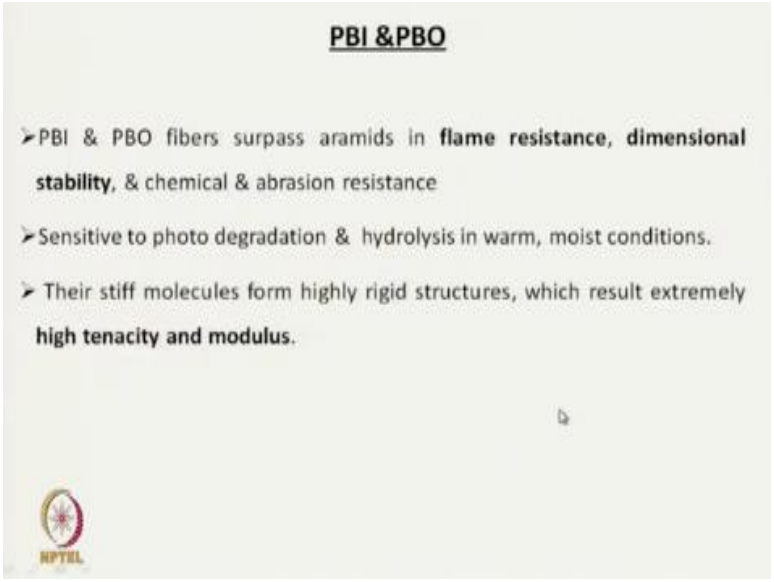

PBI or PBO fibers are used for flame retardant or fire protective clothing. So they suppress aramids in flames resistance and dimensional stability, chemical and abrasion resistance. They are sensitive to photo degradation.

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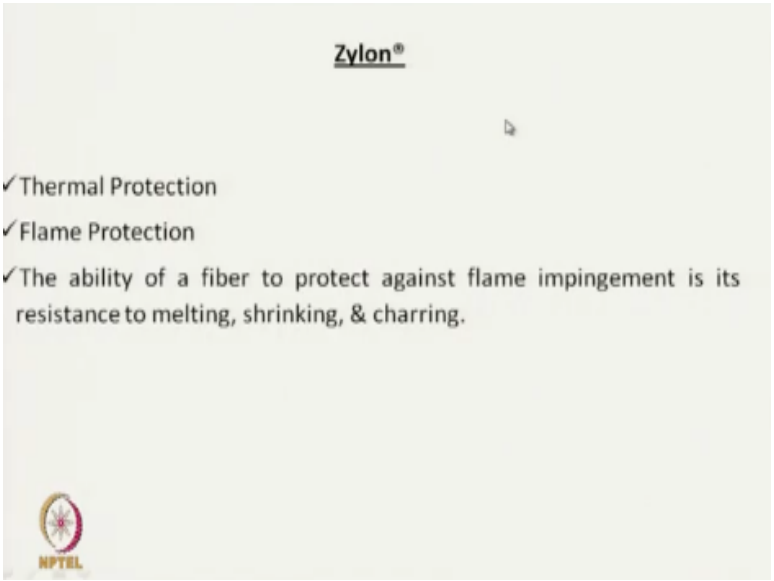

Zylon is another fiber used for thermal protective or flame protective purposes.

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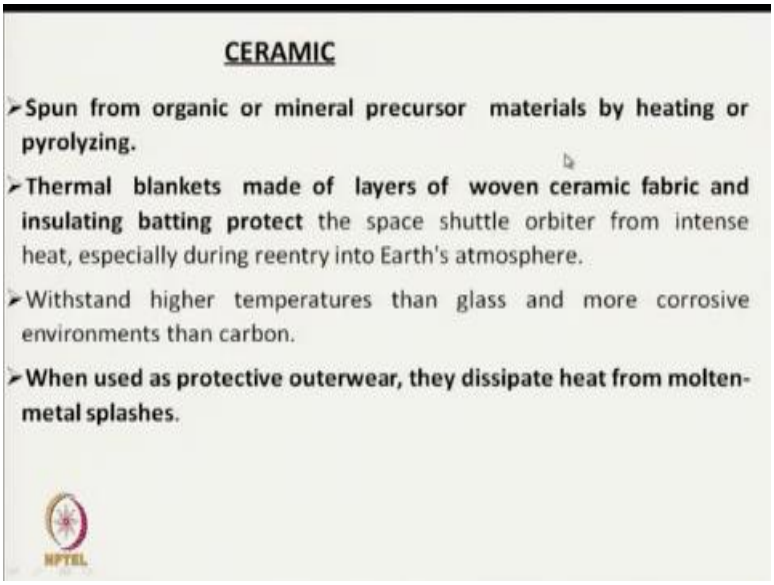

Ceramic fibers are also used, spun from organic and mineral precursor material by heating or pyrolyzing. Thermal blankets, made of layers of woven ceramic fiber and they are used for insulating purpose, so when we use this ceramic fabric as outer layer they dissipate heat from molten material splashes, so we can use ceramic fabric.

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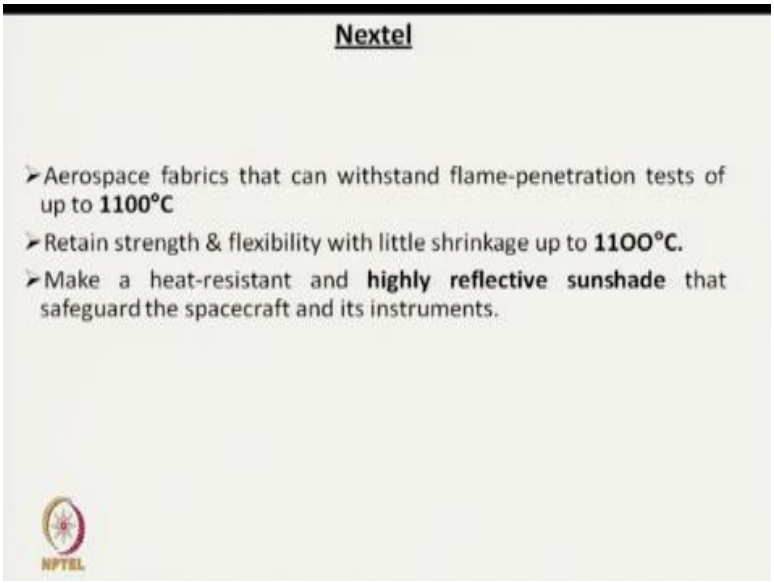

Nextel is another high performance fiber, which is flame resistant used for aerospace application.

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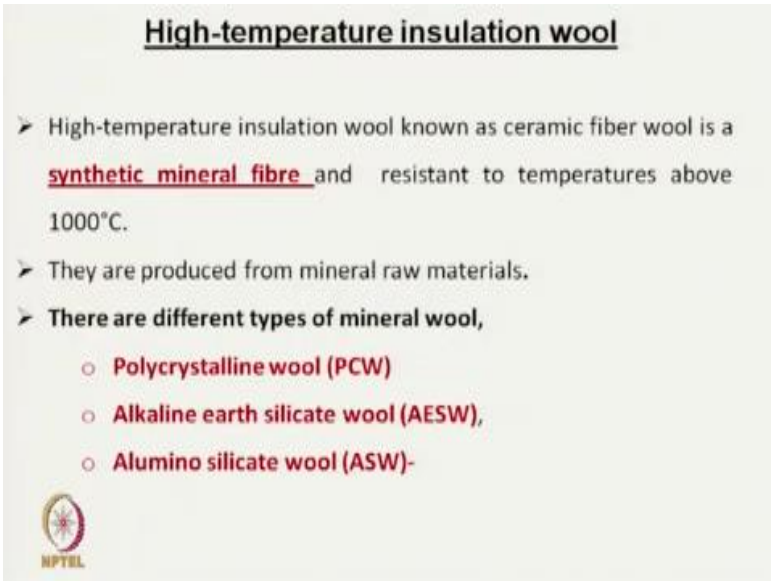

High temperature insulating wool is another type of fiber. They are made from synthetic minerals and resistant to temperature above thousand degree celsius. There are different types of mineral wool, PCW, AESW alkaline earth silicate wool, ASW alumino silicate wool, so there are different varieties of mineral wool fiber.

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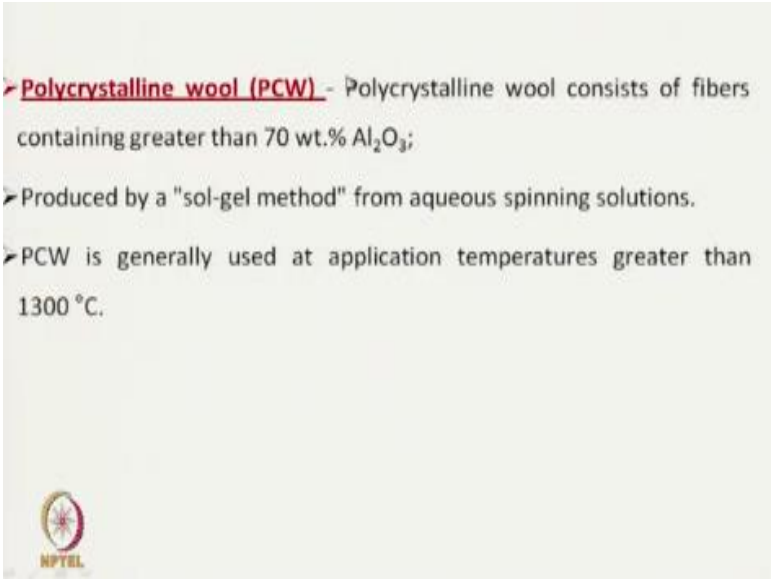

So they are manufactured from basically minerals different types of minerals, alkaline earth silicate wool or known as;

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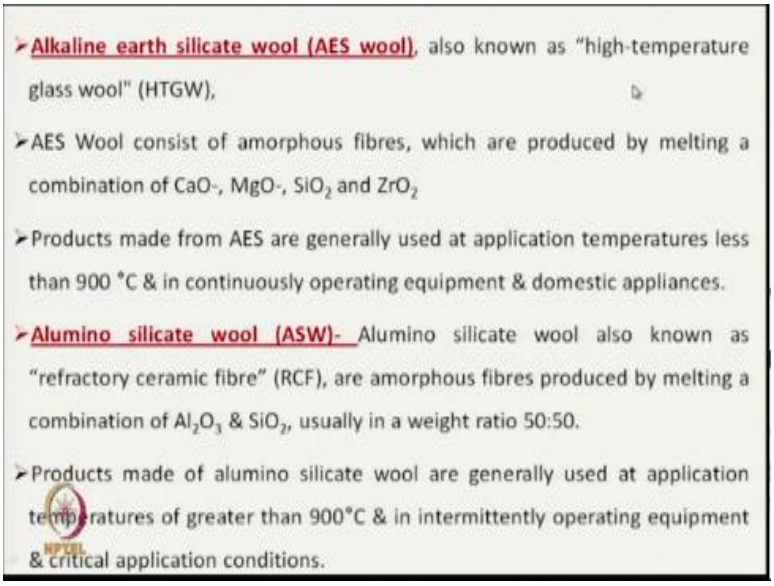

High temperature glass wool.

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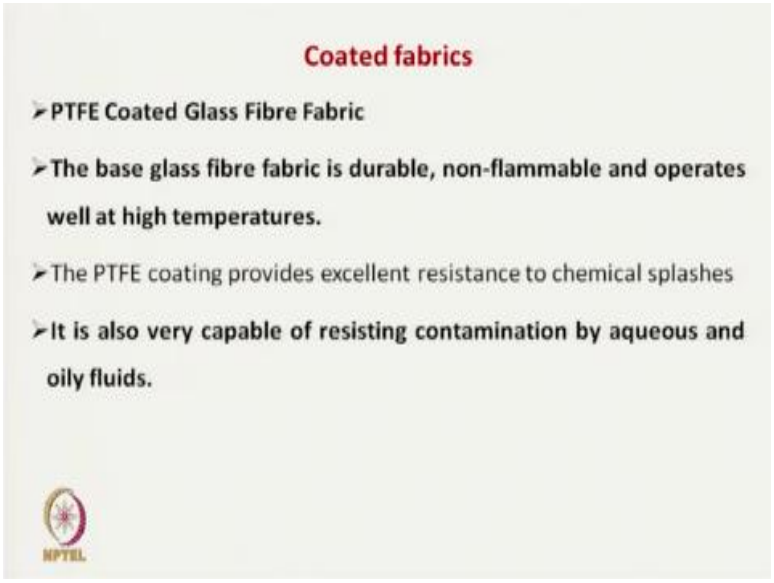

In addition to this we can use some coated fabrics also. PTFE coated glass fiber fabrics are used for fire protective clothing or heat protective clothing, the base fabric is glass fabric which is basically durable and coated with Non-flammable PTFE coating. So PTFE is also excellent resistant to chemical splashes.

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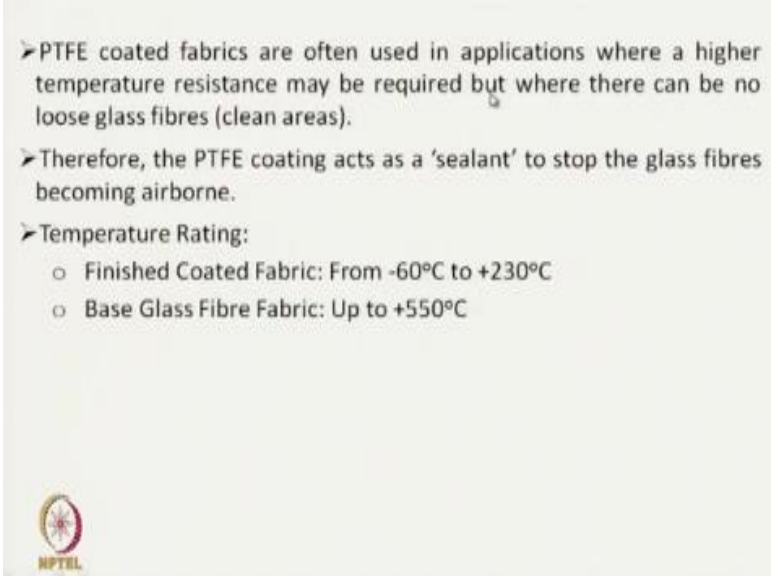

So they are used for mainly high temperature applications where the clean environment is required. So PTFE coating on glass fiber helps in preventing the shredding of loose glass fibre where contamination of glass fibers are basically dangerous. So this PTFE coating prevents the loose glass fiber to come out from the structure. This is used for clean areas, so here PTFE coating acts as sealant to stop glass fibers becoming airborne.

So that glass fiber after breaking it should not come to the environment, the temperature rating of coating is minus 60 degree Celsius to 230 degree Celsius and base glass fiber; it is up to 550 degree celsius. So, although glass fabric has higher temperature rating but this PTFE it works up to around 230 degree Celsius.

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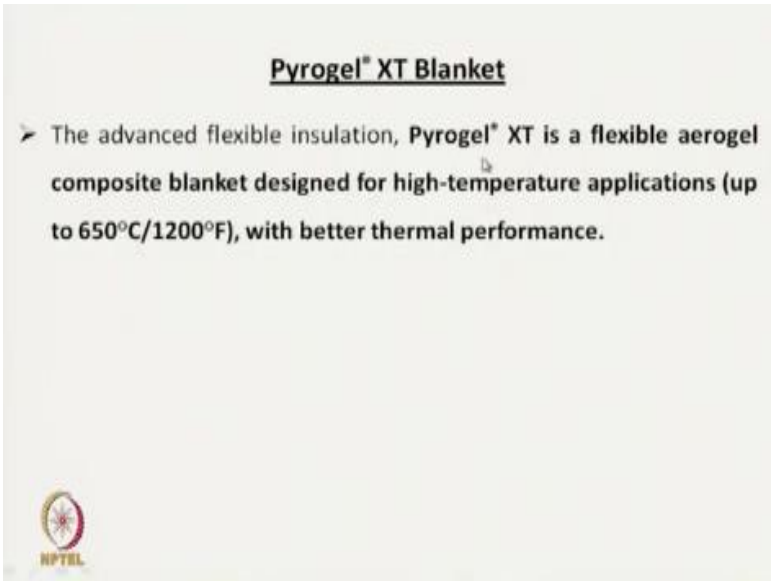

Pyrogel XT blanket, it is basically produced from aerogel, it is aerogel composite, for high temperature application.

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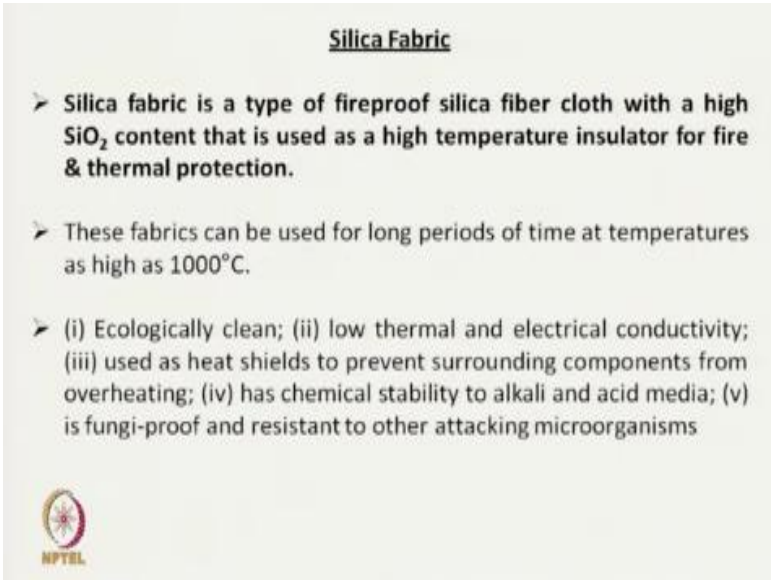

Silica fabric is also used for high temperature insulator and thermal protection.

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Some flame resistant products are where we use normal commodity fibers but these fibers have been developed, modified to make them flame resistant like fire resistant viscose and it can be blended with Nomex, modacrylic cotton blend. These are used for fire protective application or cotton can be treated with fire retardant treatment. These are the commodity fibers from which we can develop the fire protective clothing and inherently fire retardant products are Kevlar, PBI, Nomex and their blends, Nomex III A has already been discussed.

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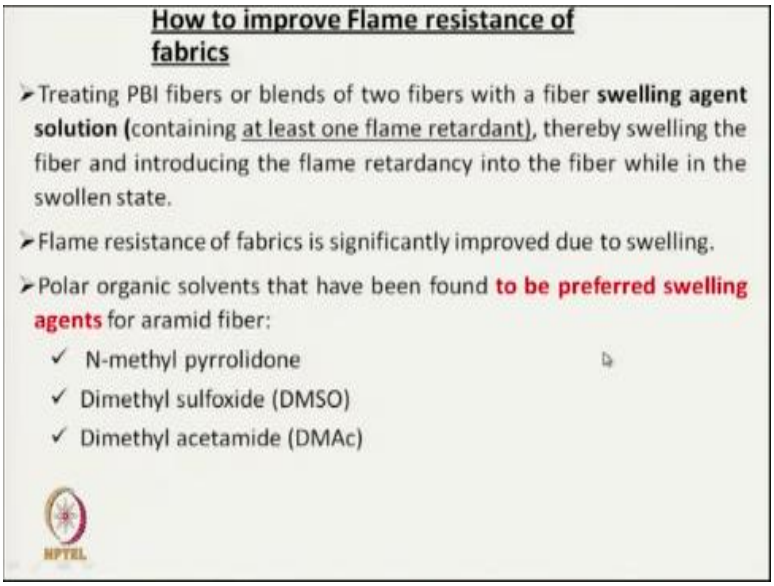

Now if we have a product and we want to improve the flame resistance in the fabric stage, there are different ways to improve the flame resistance. One of the ways is to use swelling agent, like PBI fiber or blends of two fibers, so they are inherently flame resistant and that flame resistance

characteristics can be improved by addition of swelling agent. So, what the swelling agent does with the presence of flame, these fibers will get swollen.

And this will block the pores and increase the protective performance, so polar organic solvents that have been found to be preferred swelling agents are N-methyl Pyrrolidone, dimethyl sulfoxide, dimethyl acetamide. So, these are the agents which are used as a swelling agent. So after understanding different fibers, now we will discuss the burning behavior or skin burn or thermal environment.

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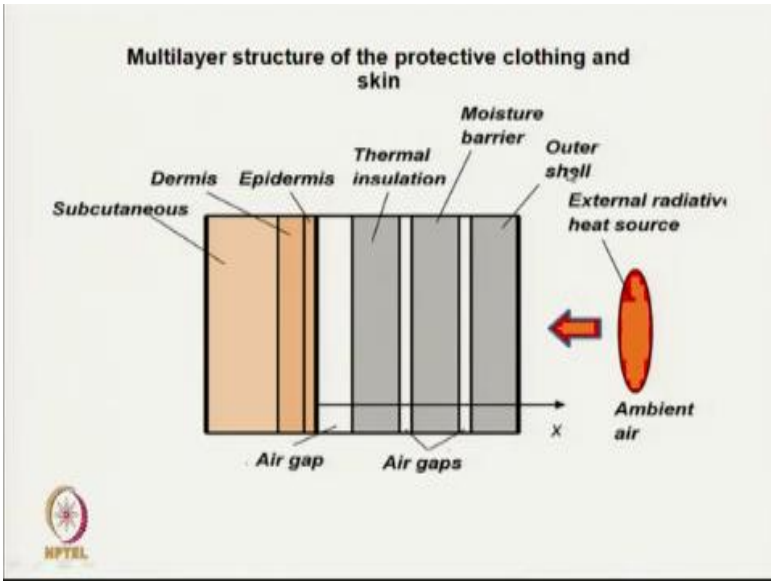

This diagram shows how heat is being transmitted from the source to our skin. This is the external source, this is the radiative heat source there could be flame through the outer layer, middle layer, moisture barrier layer, thermal insulating layer. Heat is flowing and ultimately it is coming to our epidermis, outer layer of the skin and dermis and subcutaneous fat, once the heat is flowing through the layers of fabrics and air gap.

The heat which is reaching to the epidermis is important and we must know the time required to heat flow that is called burning time. The total skin burned can be divided into six major groups.

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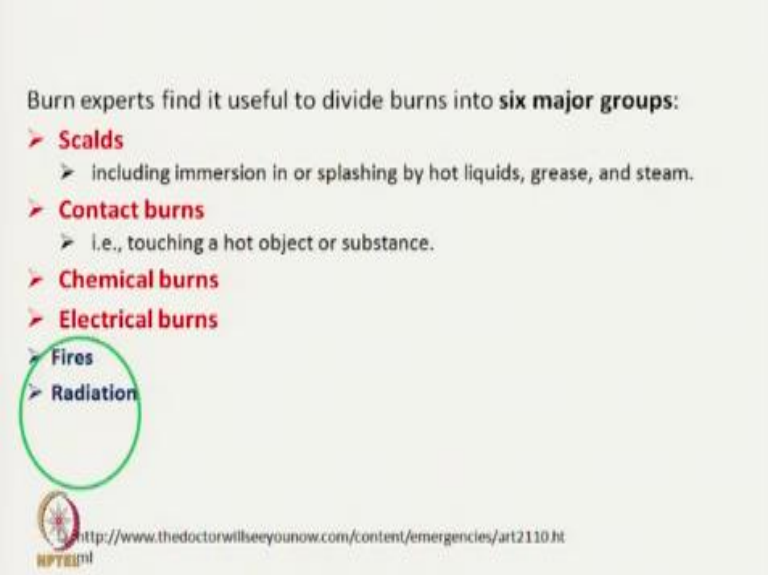

These are scalds which include the splashing of hot liquid or water or steam which is not that dangerous and can be recovered quickly. Contact burn, once we touch the hot object, so this contact burn takes place, chemical burn, electrical burn, fire and radiations. These are the different types of burns for the fire protective clothing, the main areas one should concentrate on fires and radiant heat. So if we try to see the firefighter's environment thermal environment;

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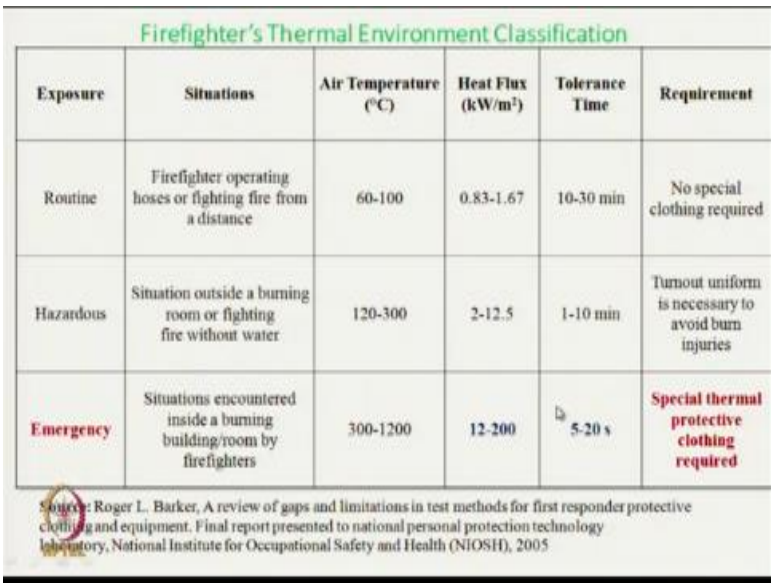

That can be classified into different groups, mainly it is three groups; routine fire exposure, hazardous exposure and emergency condition. In routine exposure, the air temperature is 60 to 100 degree Celsius with the heat flux from 0.83 to 1.67 kilowatt per square meter, tolerance time

is 10 to 30 minutes, so very high tolerance time, and that does not require any special clothing, hazardous condition, where temperature is high 120 to 300 degree Celsius with higher heat flux.

And tolerance time is 1 to 10 minute, in this case, we require some uniform but not special thermal protective clothing. But in case of emergency conditions, where air temperature is very high, it can go up to more than 1000 degree Celsius, heat flow rate is very high 12 to 200 and tolerance time is very short 5 to 20 second, where we need special thermal protective clothing. So depending on this exposure condition, we have to select our clothing.

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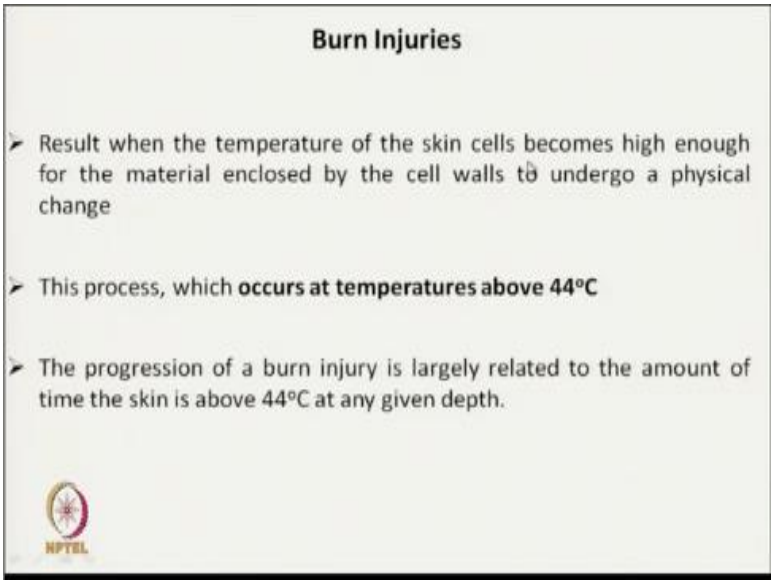

So the burn injuries it results when the temperature of the skin cell becomes high enough for the material enclosed by the cell wall to undergo physical changes. So the cell wall, at that high temperature, when it goes physical change then we will call it a burn injury. This process starts at a temperature above 44 degree Celsius.

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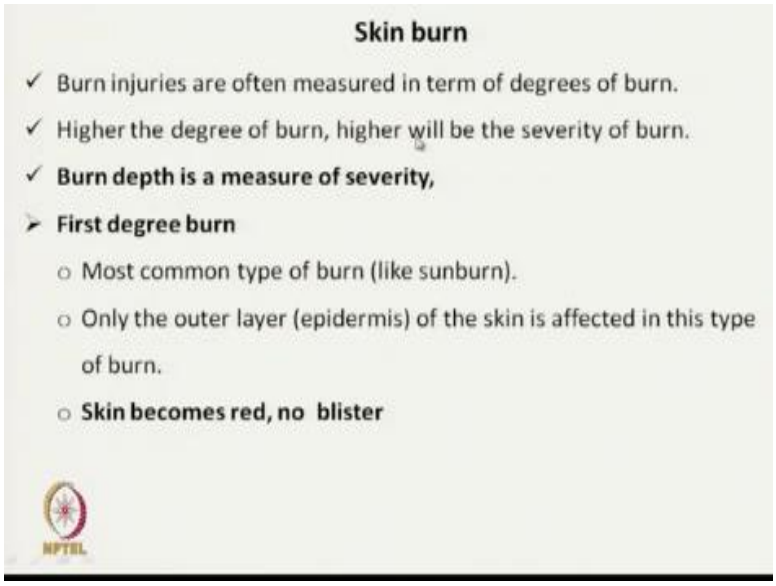

Burn injuries are often measured in terms of depth of burn and it is a degree of burn, higher the degree of burn higher will be the severity burn, so the severity is measured by depth of burn. So they are divided into three categories, the first degree burn which is the most common burn type like sunburn. Only the outer layer of the skin is affected, skin becomes red with no blister formation.

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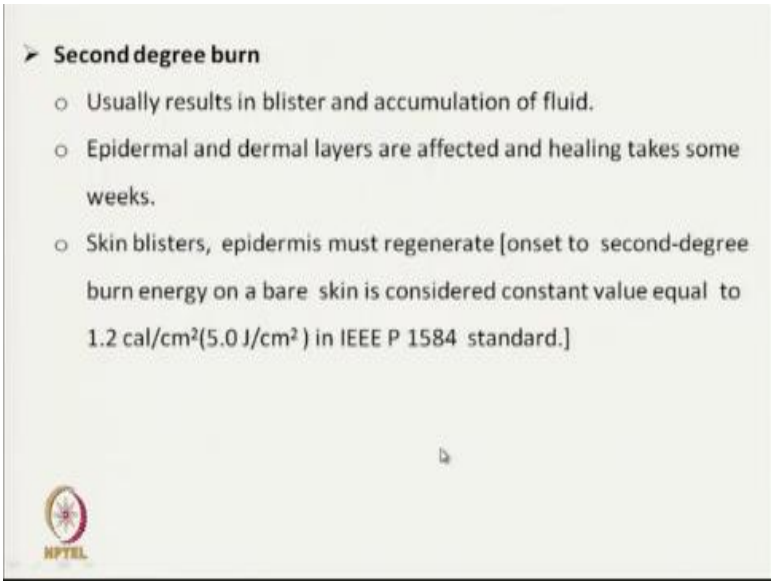

That is the first degree burn. In second degree burns usually result in blisters and accumulation of fluid, epidermal and dermal layers are affected and healing takes some time.

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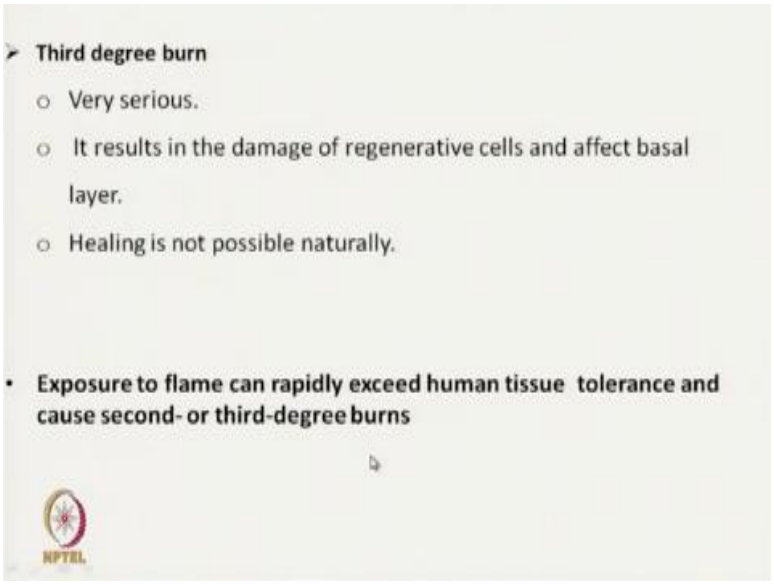

Whereas third degree burn, it is very serious. Here healing is not possible and the cell gets totally damaged. In designing the thermal protective clothing we must ensure the second degree burn, the exposure to flame can rapidly exceed human tissue, that is tolerance and causes second degree or third degree burn. So we must target to develop the flame retardant fabric which will protect us from second degree burn and the second degree burn time is the time we should keep in mind while developing the fire protective clothing.

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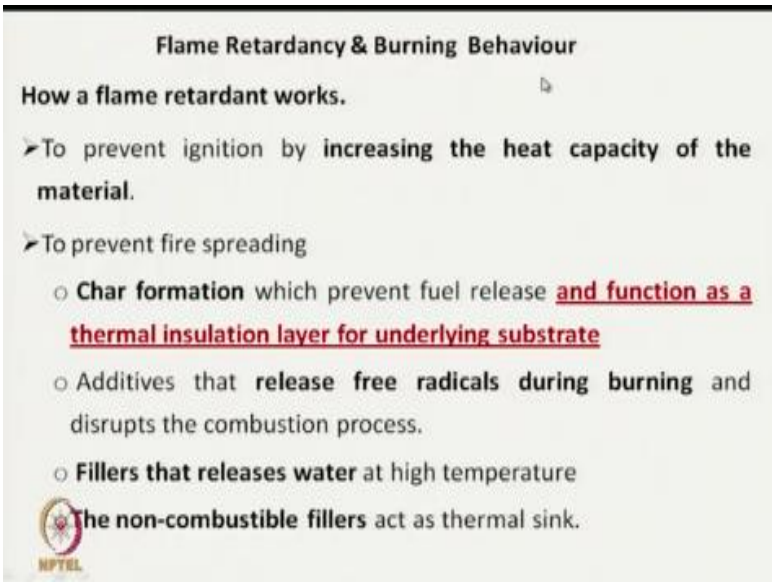

The flame retardancy and burning behavior. So if we apply the frame retardant, they work in different ways. To prevent the ignition by increasing the heat capacity of the material, so if we use the flame retardant, that means the heat capacity of the material is increased. So once the

heat capacity is increased for any flame retardant material, heat capacity is more; that means it will prevent ignition. So it will absorb the heat before ignition takes place.

Frame retardant also works by formation of char which will prevent the fires spreading. The charge formation which is actually insulating in nature, so fire spreading stops. The additives that release free radicals during burning, this free radicals disrupt the combustion process. Fillers that release water at high temperature that also prevent fire spread. So there are different blends also used.

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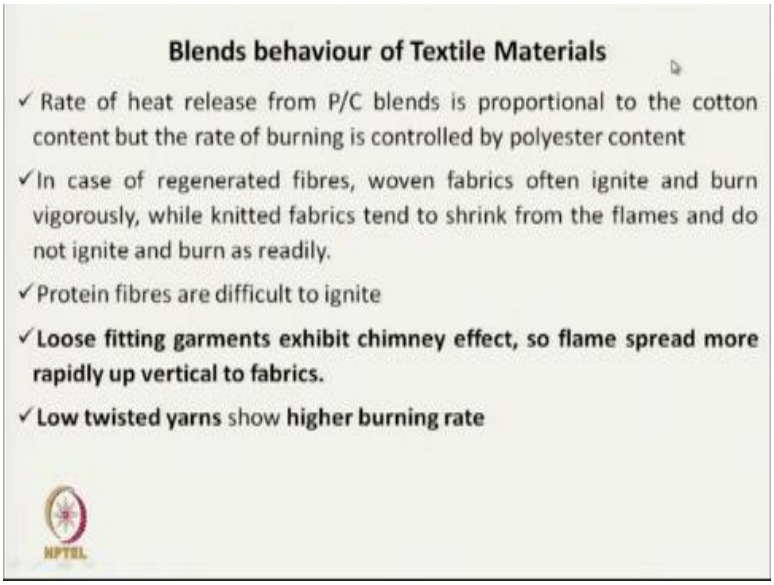

Rate of heat release from polyester cotton blend is proportional to cotton content but the rate of burning is controlled by the polyester. So by controlling the blend or type of yarn we can control the fire, like low twisted yarns can transmit fire quickly. So we use high twisted yarn where air entrapment is less. Loose fitting garments exhibit chimney effect, so flame spread more rapidly up in the vertical direction in the fabric.

We must, we sometimes use protein fiber, it is difficult to ignite. So we will stop here, in next class we will discuss the NFPA standards and different measurement techniques of fire protective clothing. Till then Thank You.