Geosynthetics and Reinforced Soil Structures
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Lecture - 3
Polymers in Geosynthetics and Manufacturing Techniques

Hello students, the previous lectures we have studied about the different types of Geosynthetics and their functions. And let us look at the different type of polymers that are used for the manufacture of Geosynthetics, and then briefly about their Manufacturing Techniques.

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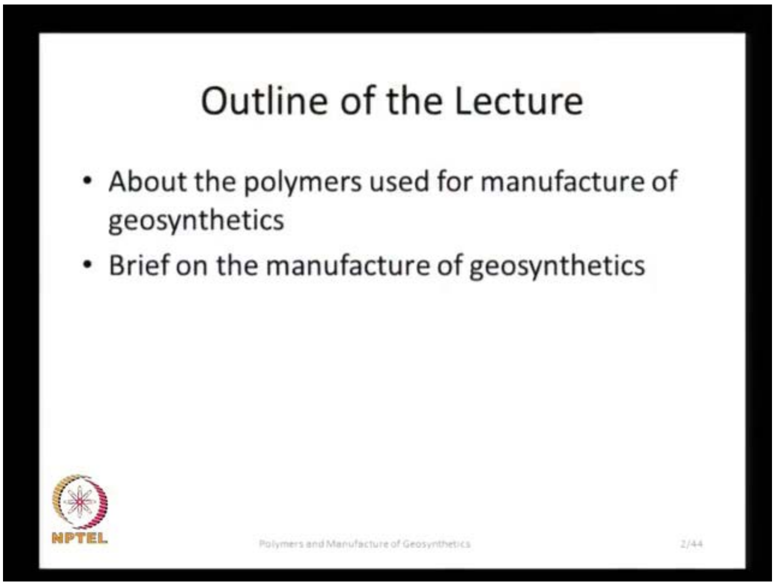

Just the outline of the lecture is will briefly look at the different types of polymers used for manufacture of geosynthetics, and then the some details on the manufacture of some type of geosynthetics.

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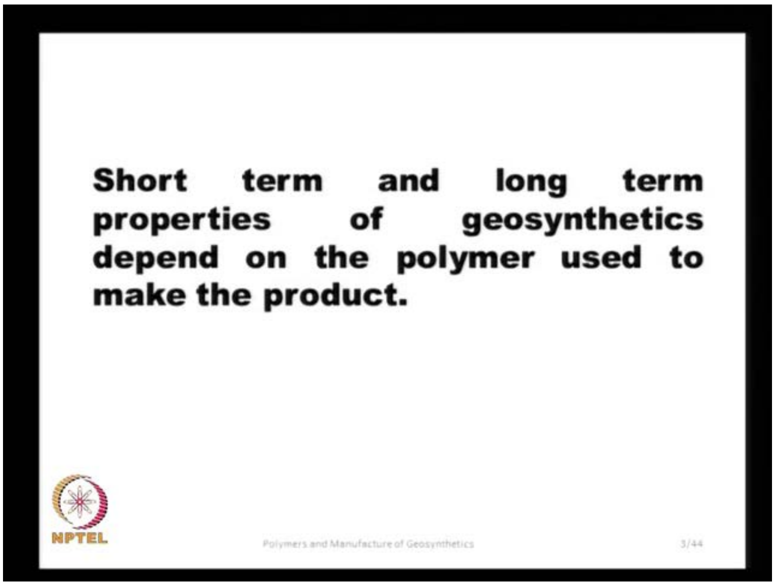

Why do we need to study about the polymers? Reason is both the short term and the long term properties of the geosynthetics depend very much on the type of polymer used for the manufacture of geosynthetics, and the manufacturing process that is used for fabricating the geosynthetic.

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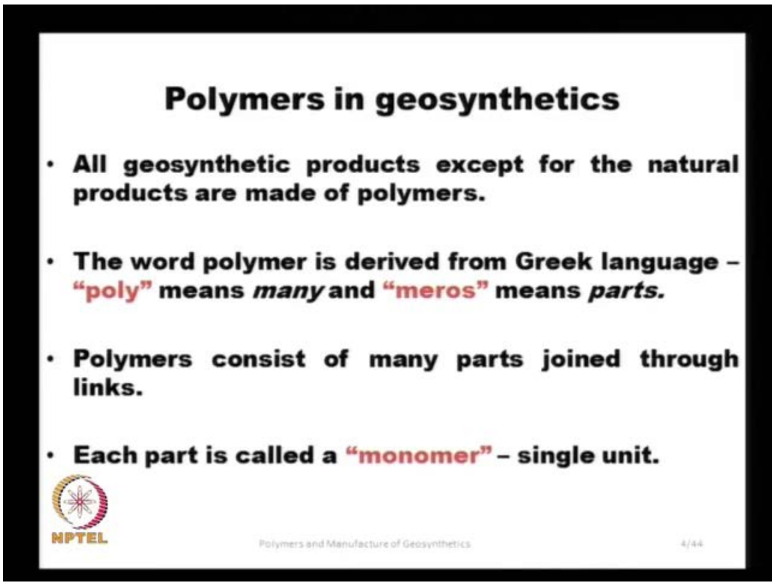

Well all the geosynthetics except for the natural products are made of polymers as we have seen the natural products are the coir and the jute and apart from these 2 varieties all others are made of polymers. And the word polymer itself is derived from Greek language the poly means many and meros means parts and basically a polymer consist of several individual poly parts, which are known as monomers, they are all joined together by some process to produce a polymer.

And then each small part as I mentioned earlier is called as a monomer and the type of polymer differs in the way the these monomers are linked together.

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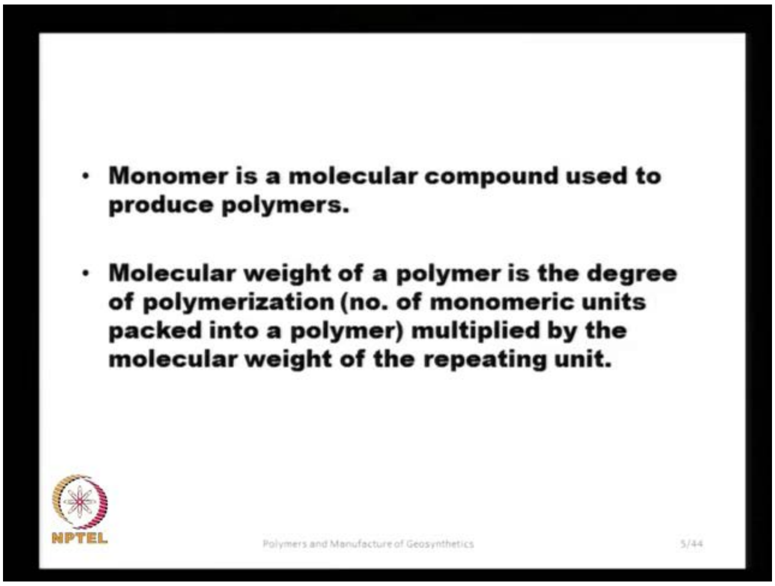

The monomer is a molecular compound is actually, it is basically the basic unit to produce polymer and the molecular weight of a polymer is the degree of polymerization. Is actually, the degree of polymerization is the number of monomeric units packed into one unit of a polymer. And the molecular weight is the degree of polymerization multiplied by the molecular weight of each of these single repeating units.

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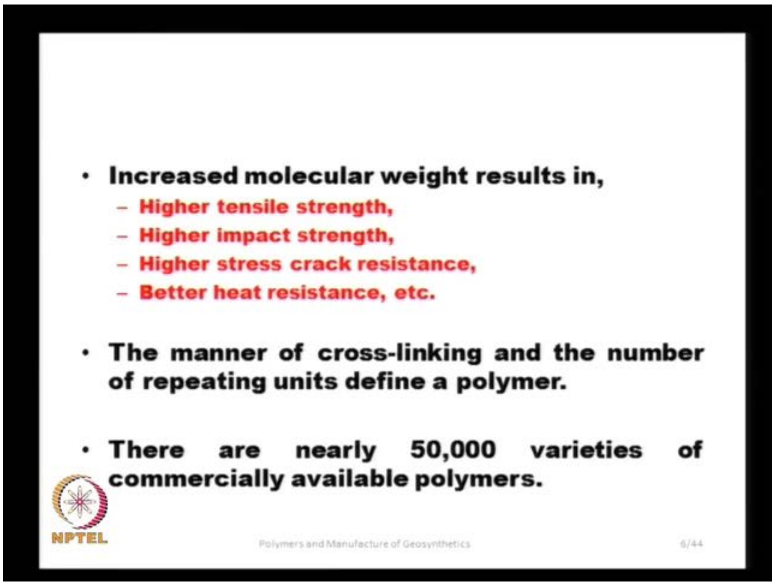

The increased molecular weight results in higher tensile strength and higher impact strength, higher stress crack resistance and better heat resistance. Basically, it means that we want to produce a geosynthetic with as much molecular weight as possible or as required to produce a geosynthetic, that has sufficient strength and other properties or in other words we can always design a required geosynthetic to have properties, that are required for our field applications. And the polymers they differ from each other by the manner in which the cross-linking and the number of repeating units or linked together. And there are a nearly 5000 varieties of commercial available polymers is actually there are very large number of polymers.

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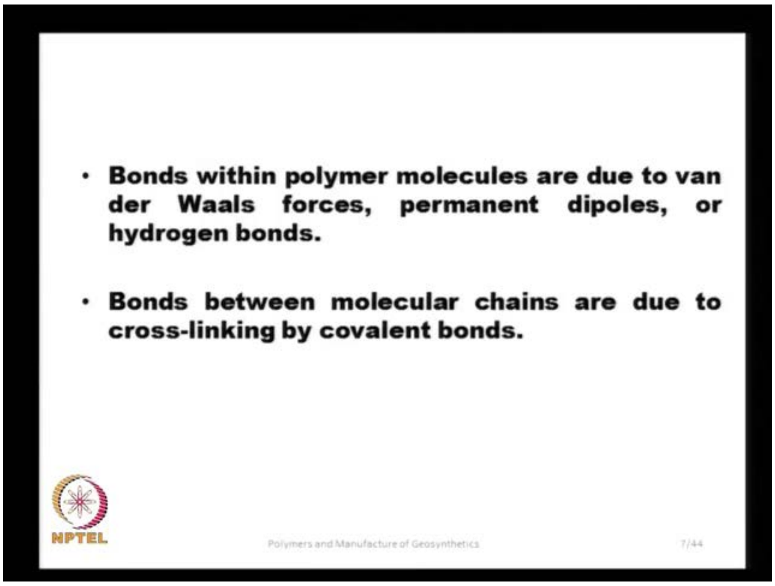

And how are these individual units linked together the bonds within the polymer molecules are due to van der waals forces and the permanent dipoles or hydrogen bonds. And the bonds between the molecular chains are due to cross-linking by covalent bonds, the actually these bonds within the polymers are very similar to what we normally study in the clay soils in terms of the secondary bonds, and then the primary bonds and so on. So, these we can imagine that, the polymer is something like a clay where in individual particles or individual units, they are all bonded together to produce a mass in the case of soils, we call it as clay, but in the case of polymers, we call it as a polymer.

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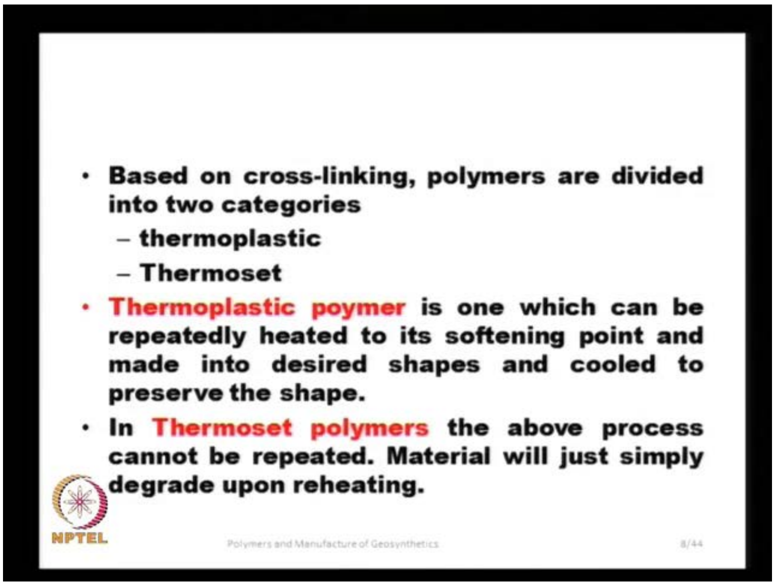

And based on the way the different monomers, they are linked together the cross-linking the polymers are divided into 2 fundamental categories, these are thermoplastic and thermoset. The thermoplastic polymer is the one in which this polymer can be repeatedly heated to its softening point and made into desired shapes and cooled to preserve the shape.

And we can repeat this process as many times as possible or as required, whereas thermoset polymer is actually, this heating and cooling process, it cannot be repeated, it can only be done once. And if you try to reheat at the thermoset plastic, thermoset polymer, it will just simply degrade and most of the or all the geosynthetics, they are made of thermoplastic type of polymer.

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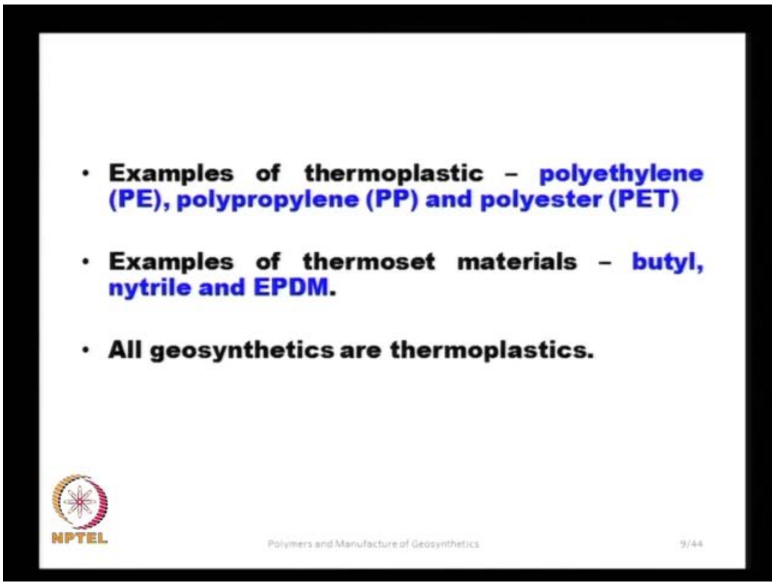

And some examples of the thermoplastics or the polyethylene, polypropylene and polyester and some examples of the thermoset materials are butyl nytrile, and EPDM and as I mentioned earlier all the geosynthetics are made of thermoplastic polymers.

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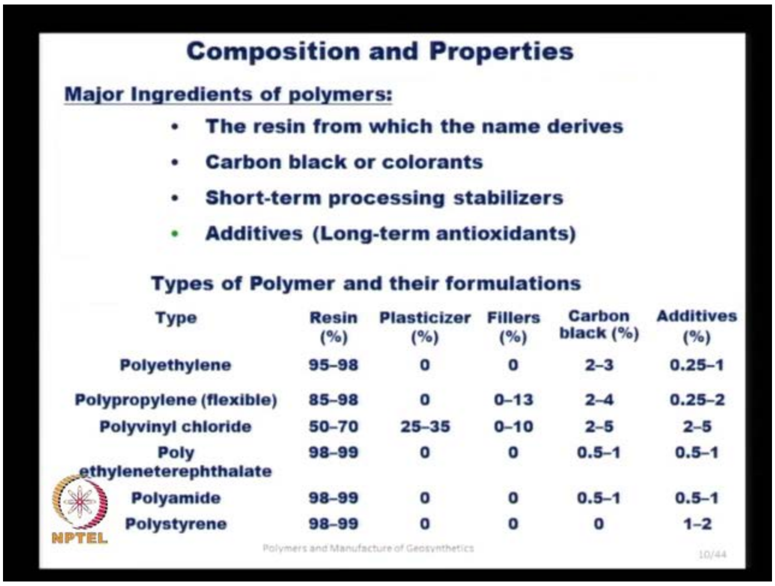

The major ingredients of polymers or the resin the that is the bulk of a polymer consist of the resin and the name of the polymer is derived from the type of resin, that is used for the for the manufacture of polymer. And then we add a bit of carbon black or coloring agent, the carbon black is usually added to preserve, it is long term properties and so that the polymer is not affected by ultraviolet rays or exposure to sunlight and so on.

And we also add some stabilizers, so that the workability short term increases during the processing time and then we also add some additives. So, that the long term behavior is improved in terms of the anti-oxidants and so on. And some of the types of polymers and their formulations are listed here and the bottom table.

The polyethylene it consist of 95 to 98 percent resin and we may add a bit of carbon black 2 to 3 percent and additive percentage is very low 0.25 to 1 percent and polypropylene, the flexible type, which is of our interest 85 to 98 percent resin. And fillers could be about 0 to 13 percent carbon black 2 to 4 percent and additives about 0.25 to 2 percent and polyvinyl chloride is about 50 to 70 percent resin.

And some plasticizers so that its workability is increased and then fillers and then carbon black and additives and so on is actually, the last varieties polystyrene is actually, the polystyrene is a very extremely lightweight material. And one form of polystyrene, that we see is all these computers and other electronic goods, they are packed in very highly durable material, which is white in color, which is very hard, but at the same time it is tough.

And that material is the polystyrene and it is resin is 98 to 99 percent and then carbon black, we do not add because it is not exposed to sun light and so on. And additives about 1 to 2 percent and polystyrene is very important material, that we use for construction of embankments and other things and extremely soft clays, because of it is light weight nature.

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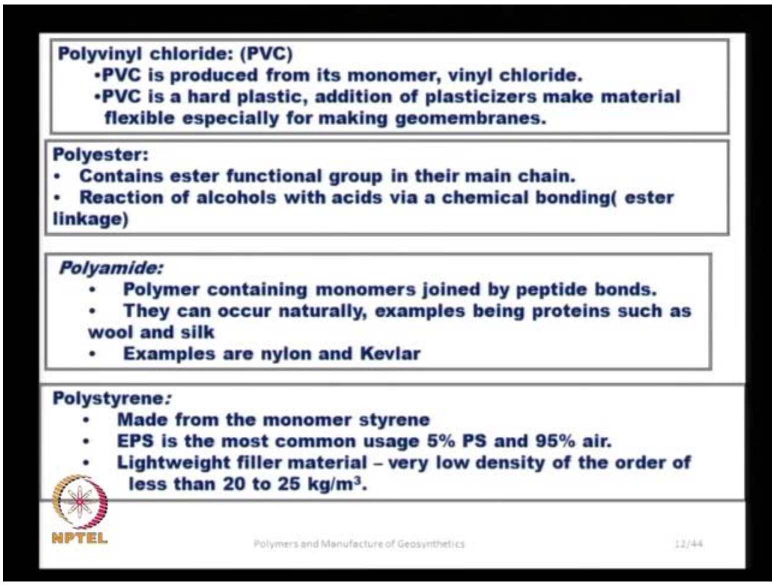

Poly let us look at the different types of these polymers, the polyvinyl chloride the P V C is produced from it is monomer, vinyl chloride. And P V C is actually, it is a hard plastic addition of plasticizes makes the material flexible, especially for making geomembranes the P V C, we see them in the form of electrical conjudes so on, we use them for domestic purposes.

And some of the geomembranes are also made of P V C's, but in this case, we need to add lot of plasticizing materials so that it becomes a flexible geomembrane. And polyester, it contains ester group of monomer or the chain material and the reaction of alcohols with acids via chemical agent, chemical bonding agent to link these ester groups. And the polyamide polymer containing monomers joined by peptide bonds and these can occur naturally, examples being proteins such as wool and silk and some polyamide products are nylon and Kevlar.

And polystyrene and it is a made from the monomer styrene and is actually, the most popular polystyrene, that is in use in geotechnical engineering is E P S or expanded polystyrene. It is a about 5 percent polystyrene and 95 percent air, because basically, we influate it by injecting hot air into notjouls of polystyrene. And it is a is extremely light weight filler material, it has a very low density of the order of anywhere from 20 to 25 kilo grams per cubic meter. So, it is literally it floats in even in water and especially on soft clays, this is a good filler material for construction of engineering structures like embankments or approach roads and so on.

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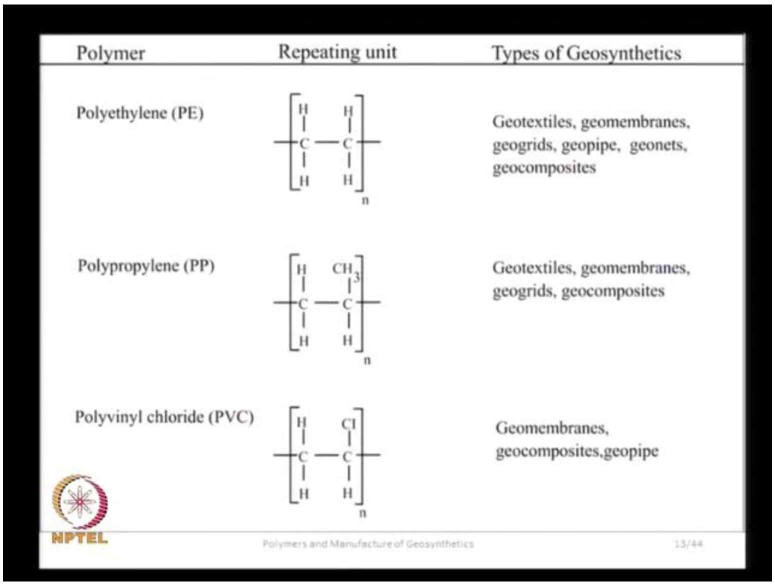

Well the different types of repeating units are shown in this table the polyethylene, it consists of H C H repeating unit and the polyethylene is used for making geotextiles geomembranes geogrids and geopipes geonets and other types of for geocomposites. The polyethylene is the common type of polymer, that is used for manufacture of stretch type of a geogrids. And the polypropylene, it consist of H C H C H 3 C H units, this is the fundamental repeating unit and the polypropylene is once again used for the manufacture of the geotextiles and then geogrids and some types of geomembranes and so on. Then the P V C is it consist of H C H and C L C H and that is the fundamental unit and that gets repeated and the P V C is used for fabrication of geomembranes and then geopipes, that is the P V C pipes and so on, then the geocomposites.

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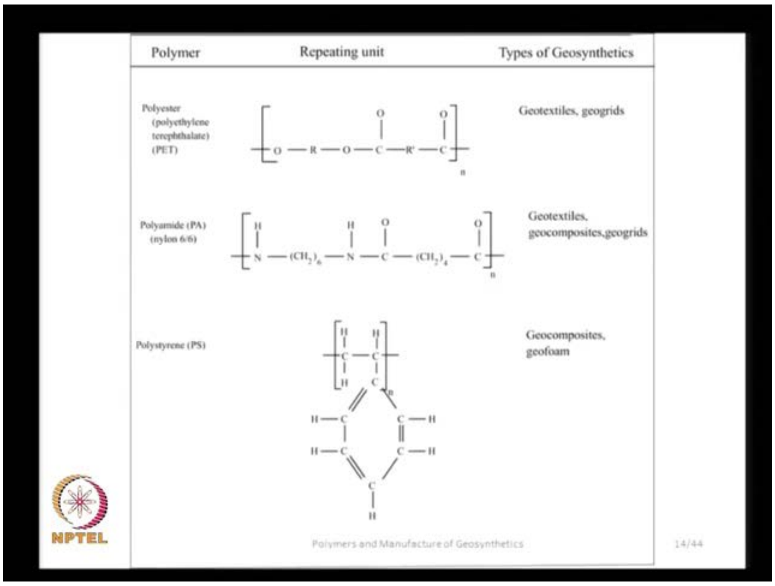

And polyester is the symbol P E T is once again, it is a very commonly used product for manufacture of geotextiles and geogrids it consist of a very long chain with the formula given here. And then polyamide once again it is a very complicated formula, so I will not repeat it. The polyamide is used for fabrication of geotextiles and geogrids and some types of geocomposites and polystyrene also has is a chain unit something like this. And the polystyrene is used for fabrication of a geofoam and expanded E P S blocks and then the geocomposites and so on.

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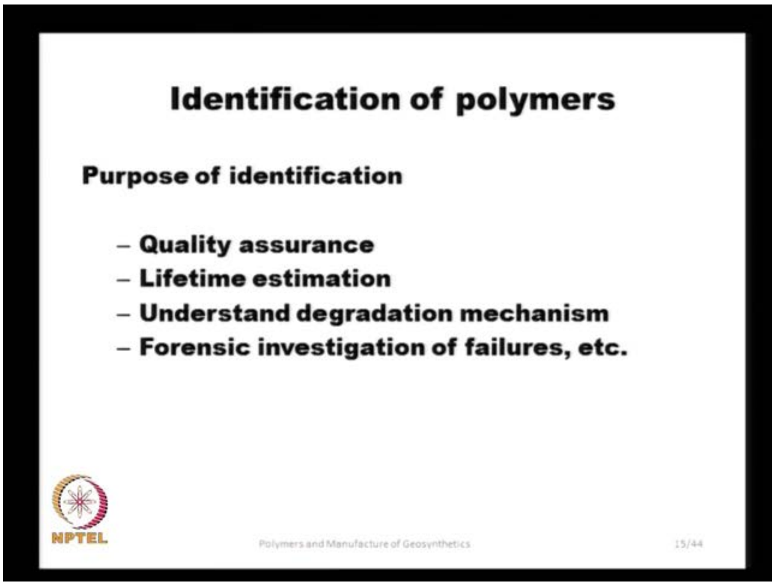

Well how do we identify a given polymer the purpose of identification is several fold, one is the quality assurance and then the lifetime estimation, because different polymers, they have different lifetimes. And we also need to understand their degradation mechanism once there installed in the in the soil and for investigating any failures the cause for any failure and so on. So, we need to identify, the type of polymer for all these purposes.

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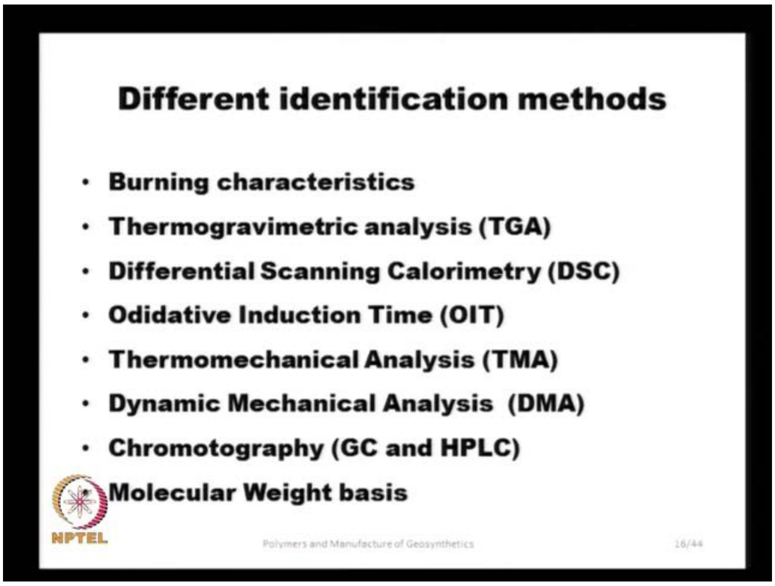

There are varieties of methods for identifying the type of polymer some of them are listed here by looking at the burning characteristics, thermogravimetric analysis differential scanning calorimetry oxidative induction time thermomechanical analysis, dynamic mechanical analysis, chromotography and molecular weight basis.

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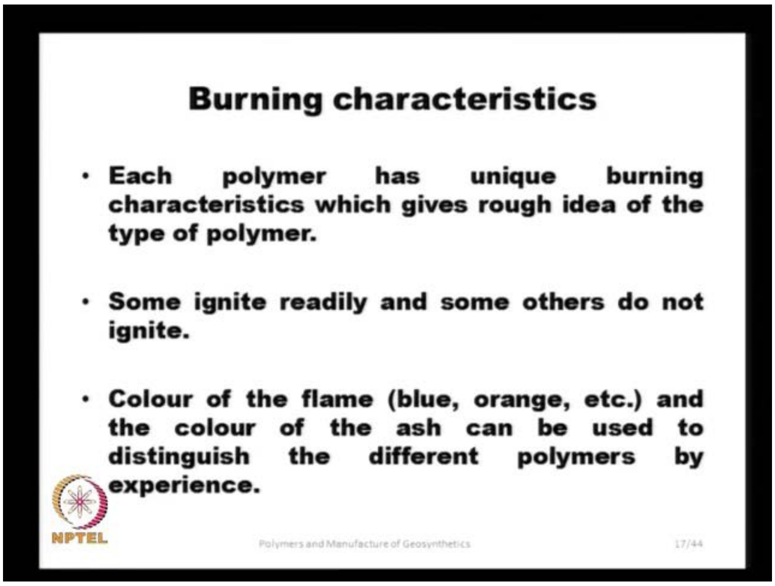

Well the simplest one is the burning characteristics, each polymer has a unique burning characteristic, which gives rough idea of the type of polymer. So, some of the polymers they readily ignite and whereas, some others do not ignite. And when they get ignited, the color of the flame is indicative of the type of polymer that is that is used, some of the colors are blue and orange and even the ash that is produced is different for different types of polymers. So, by looking at the color of the flame or by looking at the ash that is produced by the burning process, we can identify the different type of polymers and it requires some type of experience, because it is all subjective.

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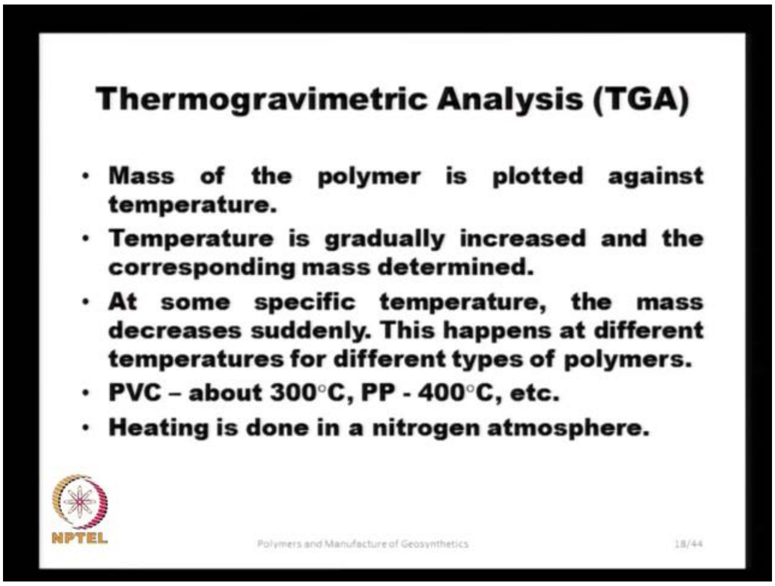

Thermogravimetric analysis here, the mass of the polymer is plotted against the temperature. And temperature is gradually increased and the corresponding mass is determined and at some specific temperature, the mass decreases suddenly. And this happens at different temperatures for different types of polymers, for example, the P V C's at the transition temperature is 300 degree centigrade where, as polypropylene, it is 400 degree centigrade. And the heating is done in a nitrogen atmosphere in a very highly controlled manner and depending on the temperature at which the mass changes, we can identify the polymers and once again, it is subjective type of analysis.

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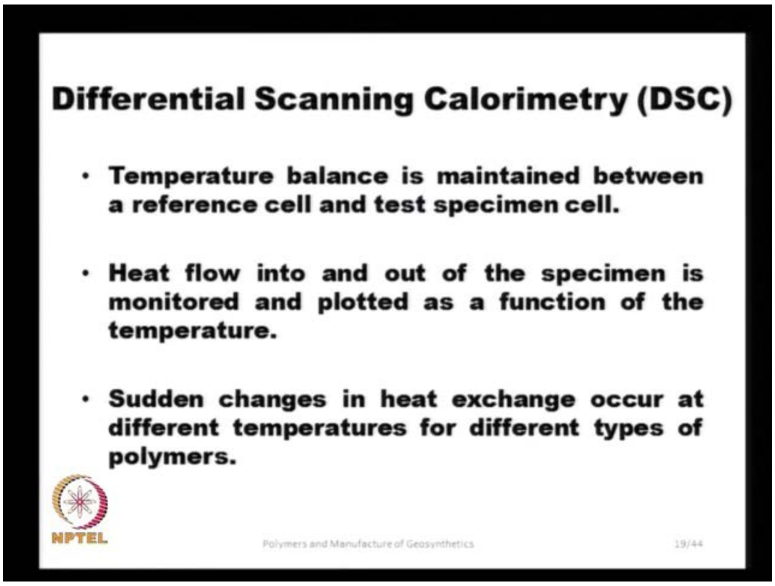

The method for identifying the polymers is a the differential scanning calorimetry the we use a temperature balance. And we maintain a the temperature balance between reference cell and a test specimen cell and we measure the heat flow into or out of the specimen and we plot it as a function of the temperature. And the sudden changes in the heat exchange occur at different temperatures for different types of polymers especially, when they are at some high temperature, the defines the transition point. And there is a sudden exchange of heat and by looking at the temperature at which the heat exchanges a very significant, we can identify the type of polymer.

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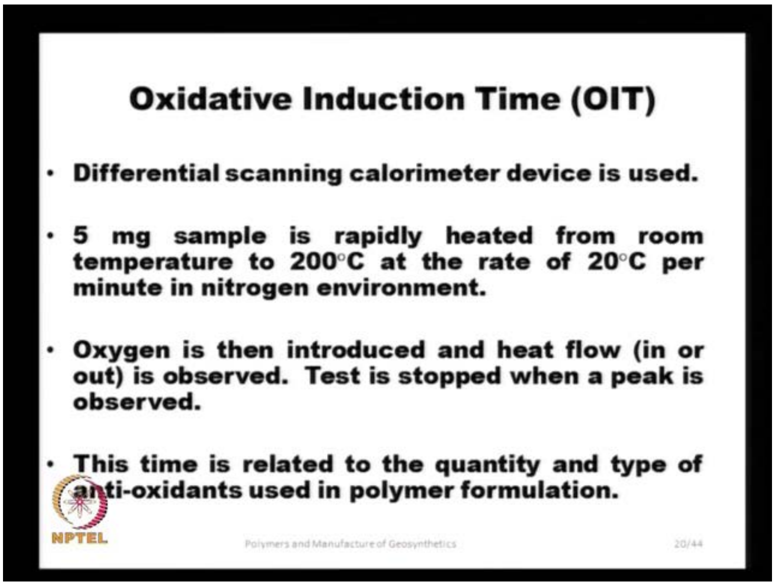

Oxidative induction time, we use a differential scanning calorimeter for this test, we take 5 milligrams sample. And we rapidly heat it from room temperature to about 200 degree centigrade at a rate of 20 degree centigrade per minute within a nitrogen atmosphere and the oxygen is then introduced and heat flow in or out is observed. And the test is stopped when we observe a peak and the time is related to the quantity and type of anti-oxidants used in polymer formulation and based on this oxidative induction time, we can identify the polymer.

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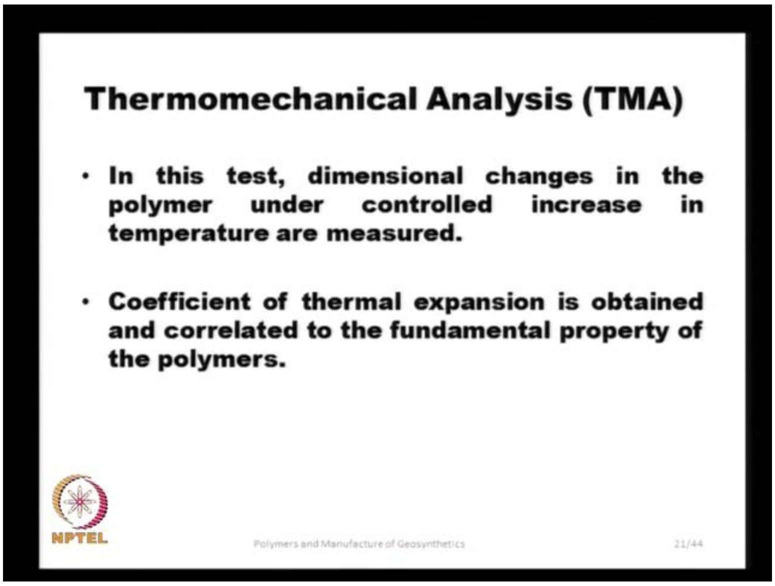

Thermomechancial analysis in this test, the dimensional changes in the polymer under controlled temperature increase is measured and the coefficient of thermal expansion is obtained and correlated to the fundamental property of polymers. Because, this coefficient of thermal expansion is a different for different type of polymers and by measuring this coefficient in this T M A, we can identify the polymer.

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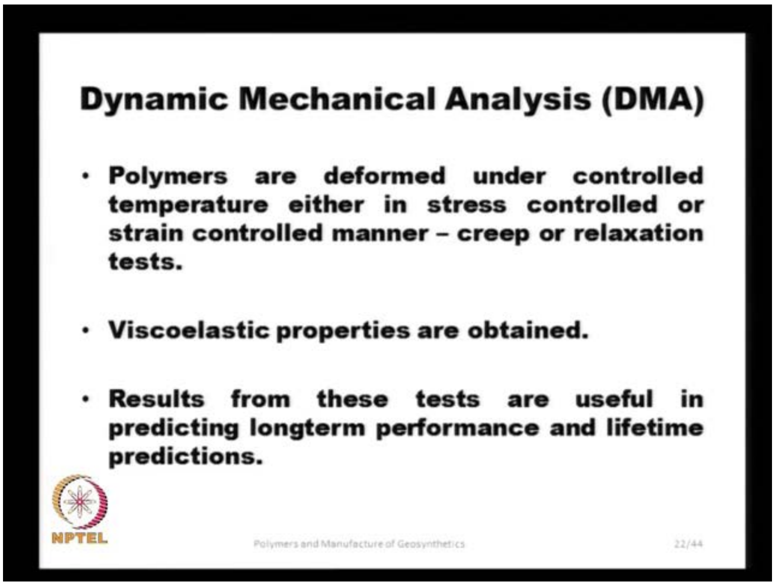

Another method for identifying the polymers is the dynamic mechanical analysis, the polymers are deformed under controlled temperature, either in stress controlled or strain controlled manner. And the we can do the creep or relaxation type of tests and viscoelastic properties are obtained and the results from this tests are useful in a predicting the long term performance. And the lifetime predictions and depending on the and the properties that we measure in this test you can identify the type of polymer because the different type of polymers, they have different viscoelastic properties.

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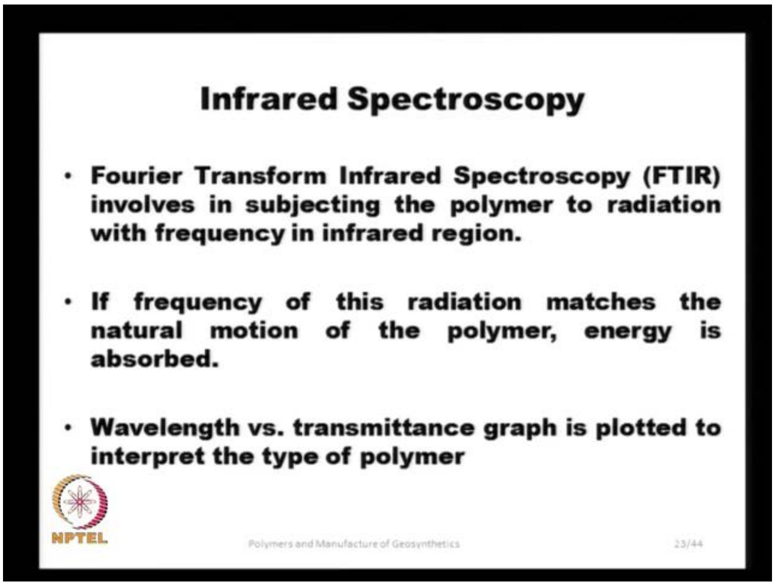

Infrared spectroscopy, we use a Fourier transform integrate in infrared spectroscopy and subject the polymer to radiation with frequency within the infrared region. And if the frequency of this radiation matches the natural motion of the polymer energy is absorbed and we plot a graph between the wavelength and the transmission. And identify the type of polymer, because once that is matching in the frequency of the radiation and the motion of the polymer, we can detect the or we can interpret the type of polymer.

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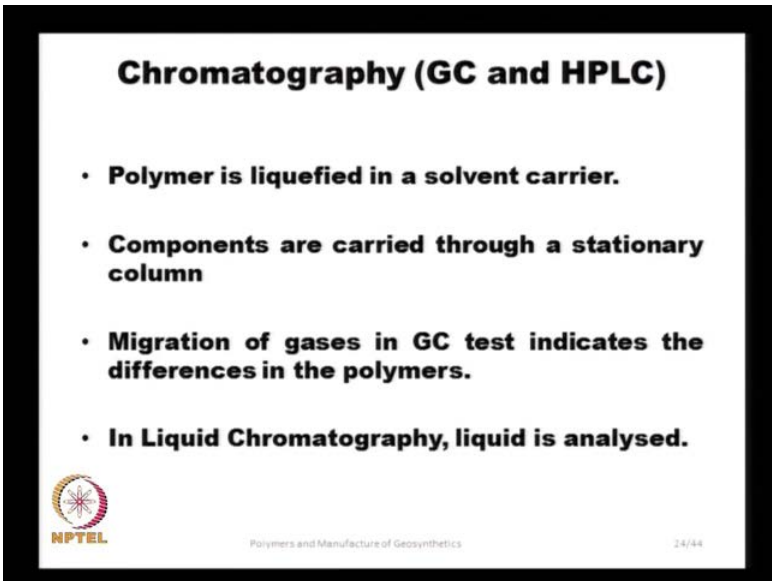

Chromatography, we can either use a G C or H P L C type of chromatography in the polymer is liquefied in a solvent carrier. And the components are carried through a stationary column and migration of gases in G C test indicates, the differences in the polymers and liquid chromatography liquid is analyzed. Because, different type of polymers, they emit different type of gases and even the liquid, that is produced by this melting process is different for different type of polymers and by analyzing either the gas or the liquid, we can identify the type of polymer that we have.

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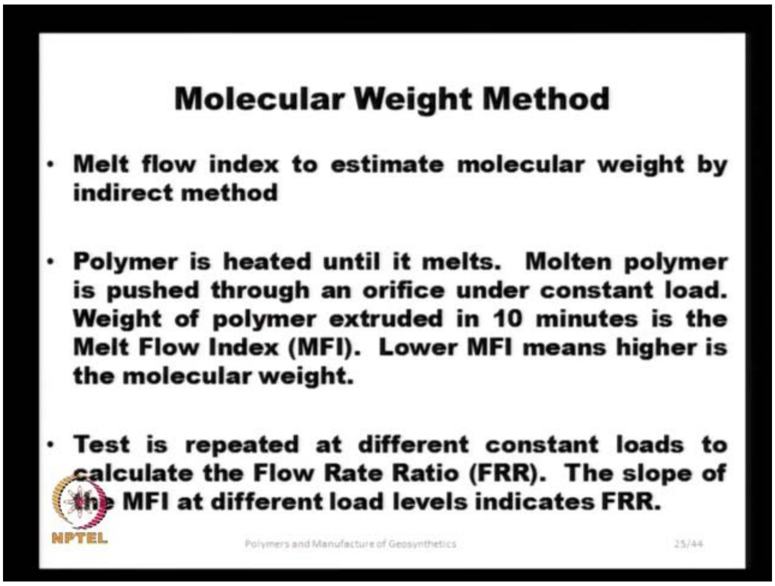

Another method is the molecular weight method, melt flow index is used to estimate the molecular weight by indirect method. And the polymer is heated until it melts and the molten polymer is pushed through an orifice under constant load and the weight of polymer extruded in 10 minutes is the melt flow index, lower M F I means, that higher, if the molecular weight. And obviously, as the molecular weight is higher, it is difficult to pass it through the orifice, because it takes a longer time and we measuring the weight of the polymer in a fixed time of 10 minutes.

And we repeat this test at different constant loads to calculate the flow rate ratio the slope of the melt flow index at different load level is called as the flow rate ratio and it is different for different type of polymers. Because, basically the molecular weight is different for different type of polymers and so either by looking at the flow rate ratio or the melt flow index, we can identify the polymer that, we have.

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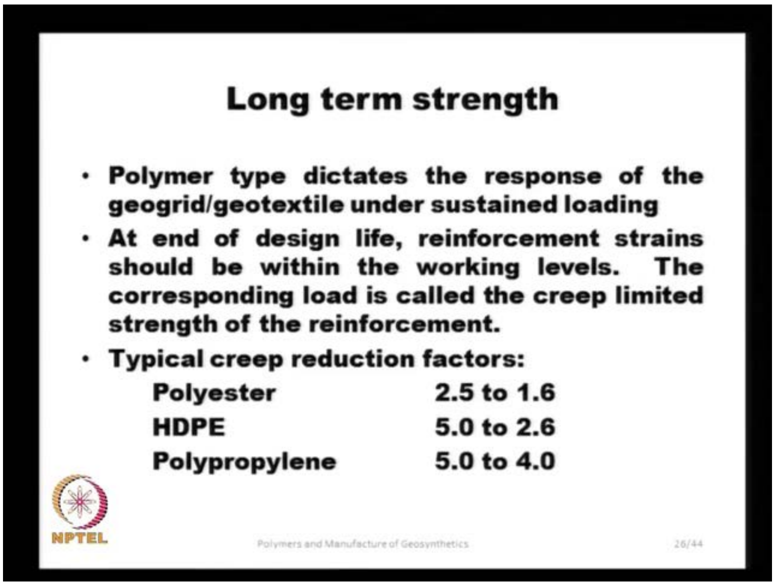

The long term strength is one of the fundamental properties that, we are interested in especially, where we have significant lateral strengths, that could happen in the case of steep retaining walls or steep embankments and other things, because they are subjected to constant loads and then the structure is free to deform laterally. And the long term properties that, we measure in in the laboratory they can be used for estimating the long term deformations.

The polymer type is actually dictates the type of response that a given geogrid or a geotextile undergoes under sustain loading is a constant loading and that the response under a constant load is called as the creep response. So, at the end of design life the reinforcement strains should be within the working levels, that could be either about 2 percent or 3 percent or 5 percent or some finite strain that is decided based on the type of application that, we have.

And the corresponding load that, we can apply to keep the strains within acceptable limits or within working levels under after the service life is called as the creep limited strength of the reinforcement. Because, there are different types of strengths that, we measure the one is the index strength, that is we subject the geosynthetic, that is the geotextile or a geogrid or a geofabric or geomembrane to quick test, quick loading and we call that strength as the index strength.

But, then when we subject the same specimen to a constant load that remains constant for a very long duration the geotextile or the geogrid may continuously along it. And that is a that, we call as the relaxation or the continuous straining process and the strain that, we have at the end of service life. The service life could be about 100 years or 100 and 20 years or it could be as short as 10 years or even 1 year depending on the life of structure, that we have. And at the end of the service life the strains should be within some limits and the typical creep reduction factors, that we apply. So, that we have adequate factor of safety for different materials the polyester anywhere from 2.5 to 1.6 percent depending on the and the manufacturing process.

It has the least creep reduction factor, that is to get the a long term allowable load, we divide the short term strength that, we get from the index test by a factor of 2.5 to 1.6 to get the creep limited strength of a poly polyester. And H D P E high density polyethylene anywhere from 5 to 2.6 and polypropylene 5 to 4, it has the highest creep reduction factors, that is if the short term strength says about 100 kilo newtons per meter. The polypropylene will have the long term strength of only about 20 to 25 kilo newtons per meter whereas, polyester, we could have as much as about 40 to about 60 kilo newtons per meter strength.

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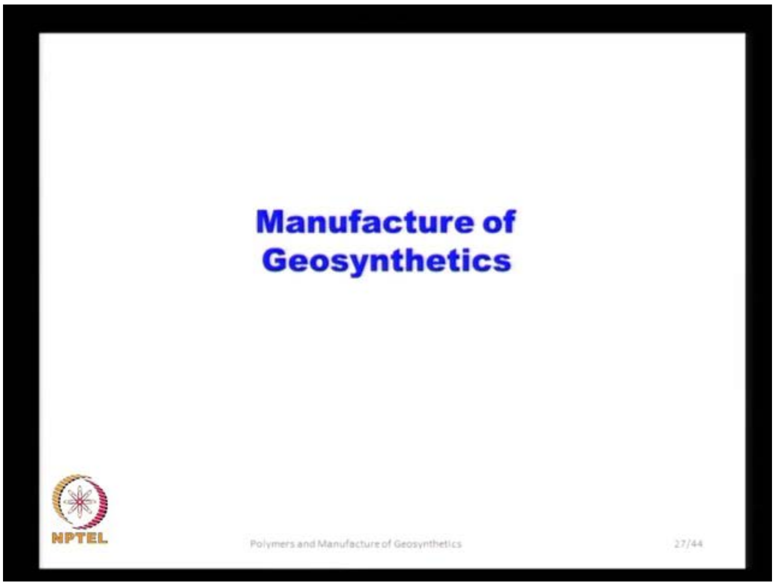

Well the previous part of the lecture has looked at the different type of polymers that, we use for manufacture of geosynthetics. The different type of polymers that, we have seen are polyethylene polypropylene polyester and so on. These 3 are the major polymers that, we use for the manufacture of geosynthetics and let us now look at the manufacture of geosynthetics.

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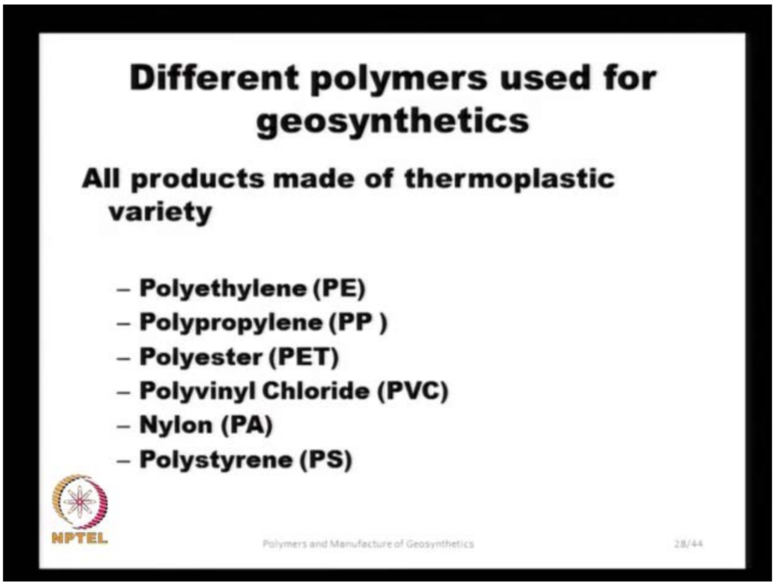

Well as I mentioned earlier or as we have seen earlier the different polymers that are used for the manufacture of geosynthetics they are all of thermoplastic variety polyethylene, polypropylene, polyester, polyvinyl chloride, nylon, polystyrene. And the first 2 types, they are extensively used for manufacture of geogrids, especially in the early dates most of the geogrids are of excluded and stretched type, they were made of polyethylene and polypropylene. And later the polyesters has come in to been and it is extensively used for fabric for manufacture of geotextiles and geomembranes and the P V C’s, they are used for manufacture of the geopipes or geomembranes.

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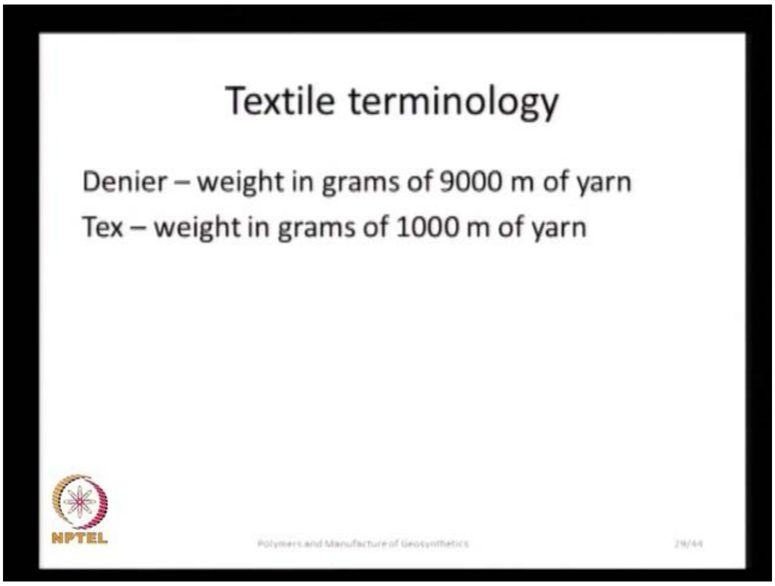

Well briefly let us look at the some of the textile terminologies, there are 2 quantities, that are frequently used for indicating the quantity of the material that is used, one is the denier. The denier is the weight in the gram of 9000 meters of yarn, yarn is the fundamental fiber or just like a piece of rope or something, that I used for fabrication of textile and the weight of weight in grams of 9000 meters is called as the denier. And another textile term that, we use is the tex, that is the weight in grams of 1000 meters, if yarn and these 2 are frequently used terms and most of the manufacturing manufactures data, they include the denier and the tex.

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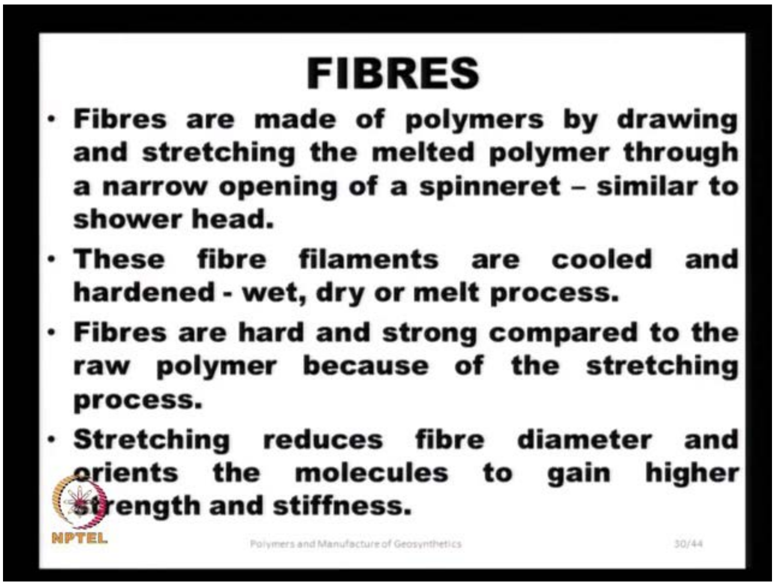

Well the fibers are the fundamental units that are used for manufacture of textiles and geogrids and so on. And these fibers, they are made of polymers by drawing and stretching the melted polymer in the polymer that we get is in the form of granules that comes from the refining process of the crude oil. And once, we get it, we melt it, we melt these polymer granules and we pass these melted polymer through a very narrow opening of a spinneret, which is similar to a shower head just like, how the water comes through the shower, these the melted polymer is made to pass through this spinneret. And then the fibers they come out in the form of thin filaments and these read cooled and 100 and then they are stretched to make them strong.

And compared to the raw polymer and because of the stretching process, basically all these the fundamental polymeric polymers the they get oriented and then process of stretching, we increase the strength. And we also increase the strength the stiffness and the stretching reduces the fiber diameter and orients the molecules to gain higher strength and stiffness.

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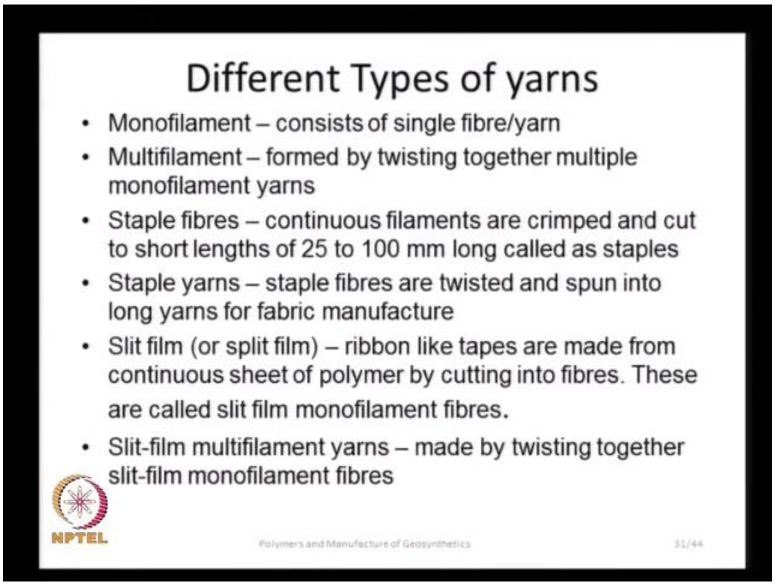

Well the different types of yarns, yarn is basically the long fiber that is used for manufacture of textiles monofilaments consists of single fiber or single yarn and multifilament, it is formed by twisting together multiple monofilaments yarns. And the other form of this the fibers is a stable fiber, it is we take a continues filament and we crimp it and cut it to short lengths 25 to 100 millimeters long.

And we call them as stables, because they are short fibers and these stables yarns are the stable fibers, they are twisted under spun into very long yarns for manufacture of fabrics, these are called as stable yarns. And the another form of the fiber or the yarn that, we use is the split film or we also call it as a split film with this looks more like a ribbon or a tape, these are made from continues sheet of polymer by cutting into fibers of required width and these are called as split films or monofilament fibbers. And we can also manufacture slit film multifilament yarns these are made by twisting together of several monofilament fibers of the earlier type.

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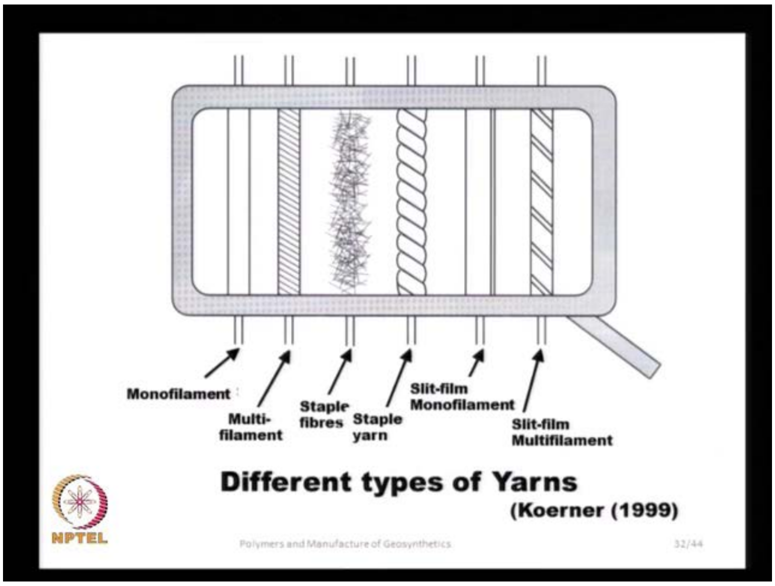

And this picture illustrates the different type of fibers that, we have the simplest one is the monofilament that consists of a single fiber or a single yarn and we can take several of these monofilaments. And then twist them and turn them around to manufacture multifilament yarns and these stable fibers, these are the short length fibers that are cut from a long from a long rope net material. And these stable fibers they are they can be wound and made into rope like structure this is called as a stable yarn and then the slit film monofilament, which has a considerable width, which looks more like a ribbon and a slit film multifilament, we can combine several of these slit film monofilament fibers to manufacture slit film multifilament fiber.

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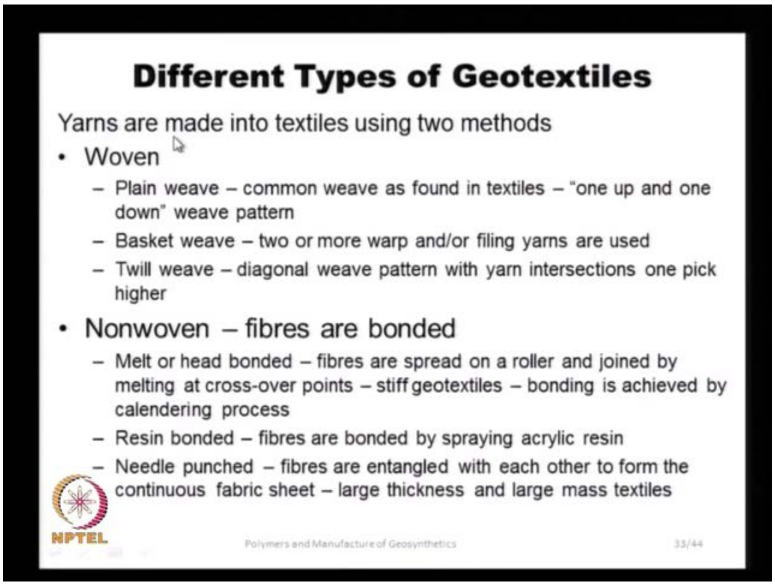

And these fibers they can be used for manufacture of different types of textiles the yarns that are discussed previously, they are made into textiles using 2 different methods one is the weaving process and the other is some type of bonding process. And the geotextile, that is made by weaving process is called as a woven geotextile and most of the high strength geotextiles they are of woven type, because they give necessary strength and the different types of weaving patterns of the woven geotextiles are the plane weave.

This is the common weave as we find in textiles the textiles that, we were like in the form of shirts pants and other things these are all. These all have a plane weave pattern it is also called as 1 up and 1 down type of weave like, we take continues yarns and we weave them together to fabricate the textile. And the other form is the basket weave, we take the 2 or more warm warp under filling yarns to formulate to fabricate this fabric and then it will be is actually, we introduce a diagonal yarn to get different shapes. And usually, this has a higher thickness lightly, because that at wherever that junction, wherever there is an intersection the fabric is slightly higher so that there is twill pattern.

And these woven geotextiles, because they are, we can control the number of yarns in a unit volume or in unit width, we can control the strength, we can design the woven geotextiles to achieve desired strength and there are other types of geotextiles, which are non, which are known as non woven geotextiles here, this fiber are bonded together. And this bonding basically, it happens in three different methods, the melt or heat bonding the fibers are spread on a roller and joined by melting at cross over points.

And we produce relatively stiff geotextiles by this process basically we take fibers. So, polymeric fibers and when we heat them they melt and then we establish the boding by melting. And then we do a calendaring process to achieve a smooth finish, the calendaring process is very simple, we pass the geotextile that is produced in the previous step a through hot rollers the heat could be different for different type of polymers.

So, that we get a smooth finfish and that bonding is achieved because of the heating process and other process of binding the fibers is the resin binding. The resin binding is we spray some acrylic resin to bind the fibers, the thickness of the bonded and the heat bonded the resin bonded and heat bonded fabrics is relatively low and the stiffness could be high depending on the type of resin, that is used for bonding. And depending on the heat that, we use for in the heat bonded textiles.

The other type of bonding the fibers is the needle punched needle punching process here, we take bunch of fibers and then we knit them together like basically, we use number of needles, that are closely packed and then we entangle the fibers together to form the continues mass. And the needle punching process is used for fabricating nonwoven geotextiles of large thickness and also having a large mass. And some examples of this needle punched geotextiles are our carpets, because they are very thick and they also have a heavy mass.

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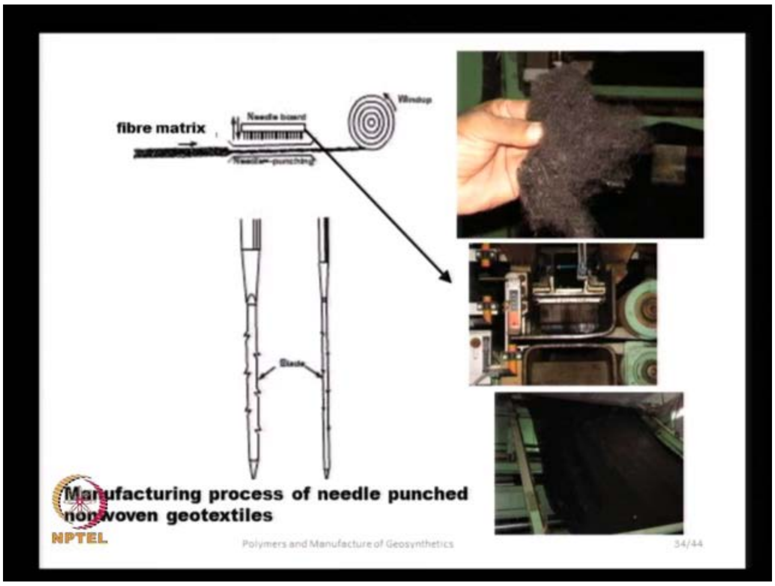

Is actually this photograph indicates the process of producing needle punched geotextiles, we take the fibers matrix and the we pass it, through a needle punching machine. Basically here, you see number of needles together and they just simply they punch through this fiber matrix and joined them together and here on the right hand side you see this machine with number of these needles. And there are these needles are typically, 50 to 70 millimeters long and they bind these fibers together and finally, they are they pass through some heating elements and then they are rolled together. And in between we also do some stretching process, because basically the stretching process it give some strength and most of these needle punched geotextiles, they have very low strength, but then they have very high mass and high thickness

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And here, we see the different types of geotextiles being manufactured the here it is a white colored geotextile, here its black color geotextile, basically the black color is because of the addition of the carbon black and all these products they are rolled and packed for shipping purposes. So, that there is very minimal damage and the packing should be. So, that they are not expose to light or heat or sun rays, because most of these products they are sensitive to ultraviolet degradation. So, this packing should be carefully done and usually, they are stored in dark rooms. So, that they are not exposed to light.

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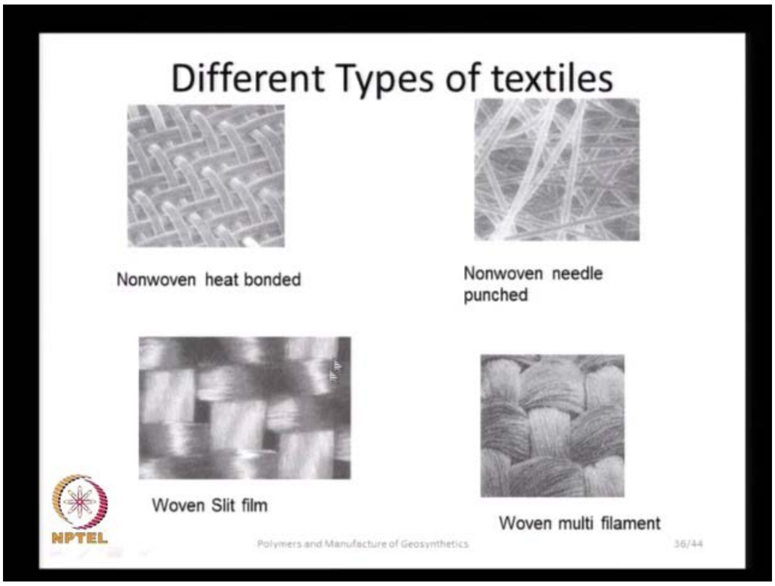

And here we see some scanning electronic microscopes of different types of textiles here, we have a the top left hand side, we have the nonwoven heat bonded geotextile and here, we have a needle punched nonwoven textile and here, we have a woven slit film geotextile and woven multifilament textile. And usually the woven geotextiles, they have apertures aperture openings of a uniform size whereas, nonwoven geotextiles, they have very large number of different types of apertures, because the openings the process of manufacture itself is different. Because of this needle punching process and because of the stretching process that is involved the we have large number of openings and we also have these openings of variety of sizes.

And so when it comes to drainage and filtration applications there could be difference in the way, we apply and nonwoven product and a woven product. Because, the woven product, because it has typically, of smaller size apertures openings and single sized openings they get clogged very fast soon enough whereas, nonwoven geotextiles, because they have multiple size of apertures and very large number of aperture openings they take much longer time to clog. So, when it comes to the filtration and drainage applications the nonwoven geotextiles, they are preferred whereas, the woven geotextiles, they are better preferred for separation application and where the strength is an important factor.

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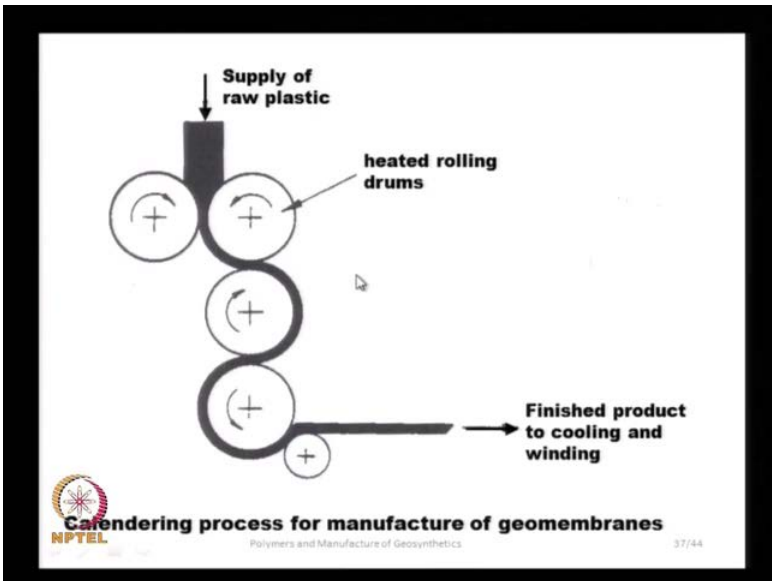

And this slide shows the procedure for manufacture of geomembrane basically, we take a sheet of polymeric material either H D P material or P V C material. And we take it through a series of hot rolling drums, which are rotating against each other and we stretch this raw sheet of polymers and it goes through several stages and we get finished product. And finally, this the finish product is cooled and then its wound to different sizes typically, all these geotextiles and geomembranes, they come in widths of anywhere from three to five meters and of lengths up to hundred meters long.

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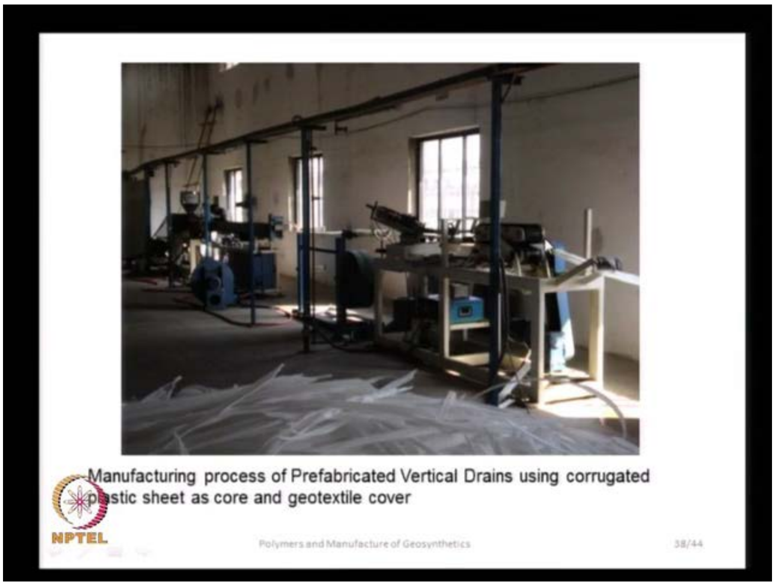

And here we see a picture of the manufacture of prefabricated vertical drain, basically these P V D's are the prefabricated vertical drains, they consist of a core that allows for the dryness of the water. And then they consists of a cover, that is the filter cloth to allow the water to flow into this drain and to keep out all the soil particles. And here we see these plastic core made of the core is made of corrugated plastic sheet and it is passed through, this machine is actually, it is these plastic sheets, they are passed through this machines to form the corrugations. And then it is covered within a geotextile cover and to fabricate this P V D's and once again, these P V D's, they come in lengths as much as 100 meters.

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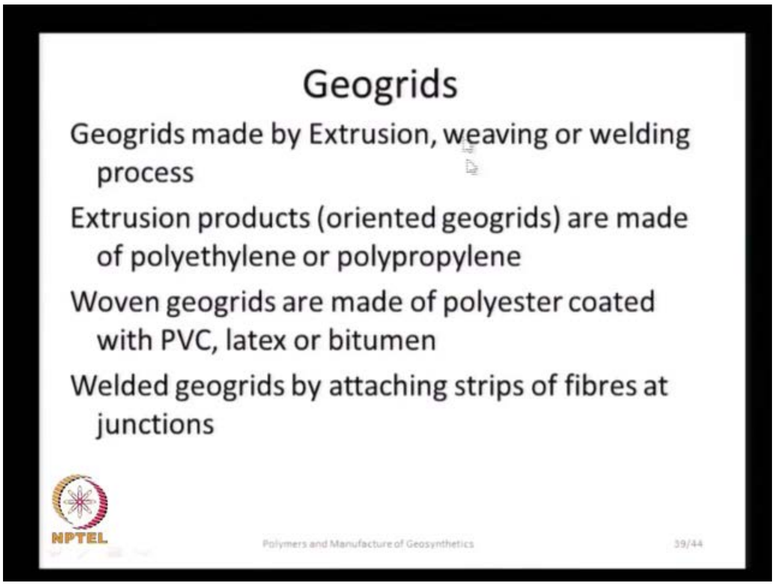

And another class of geosynthetics that are extensively employed are the geogrids and the geogrids, they are manufactured by extrusion, weaving or welding process and the excluded products, these are made of polyethylene or polypropylene. And usually, these excluded products, they have oriented molecules then the woven geogrids, they are made of polyester fibers and coated with P V C's or latex or bitumen to stabilize them against U V light or to protect the fibers against installation damage. And we also have welded type geogrids, which attach the strips of fibers at junction.

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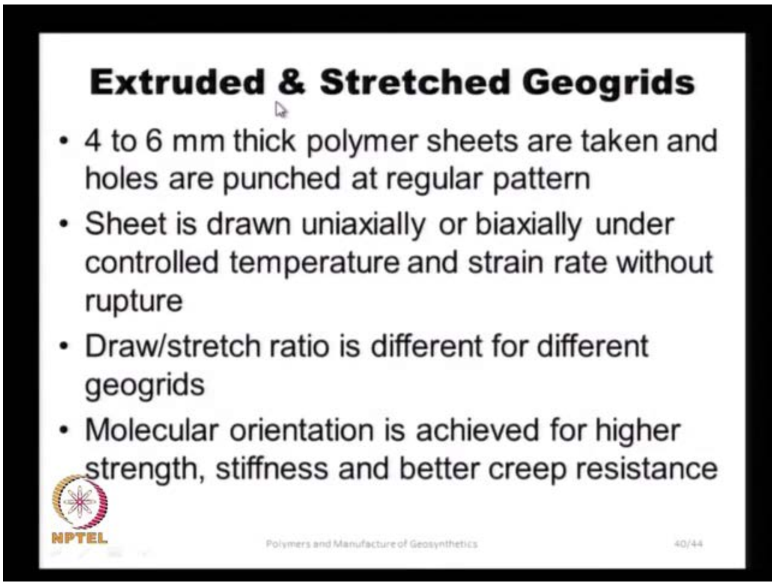

They excluded and stretched geogrids, they are manufactured by stretching a polymeric sheet that is about 4 to 6 millimeters thick and then we punch holes at regular pattern. And we the sheet is drawn uniaxially or biaxially under controlled temperature and strain rate. So, that it does not rapture in the process of stretching. And the draw or the stretch ratio is different for different types of geotin geogrids, basically the more, we stretch the more stiffness that, we give to the product and higher strength is also important, because we are orienting the molecules in certain preferred directions. And for achieving geogrids of different strength, we can we can vary the stretch ratio and the higher molecular orientation results in higher strength. And stiffness and also better creep resistance, that is long term strength is higher, if there is a good molecular orientation.

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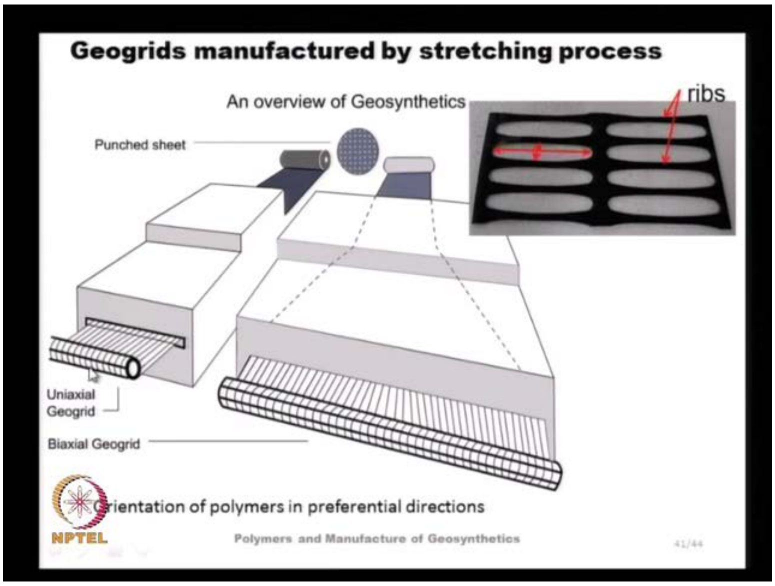

And the process of stretching is illustrated here, on the left hand side, we see the uniaxial stretching, we take a polymeric sheet and we punch holes and then we stretch it through this machine that stretches while heating and passing through different type of rollers. And if you stretch the this sheet in 2 directions, we have a biaxial geogrid, that has strength the significant strength in a 2 different directions and in this inset, we see a uniaxial geogrid, that is manufactured by this process.

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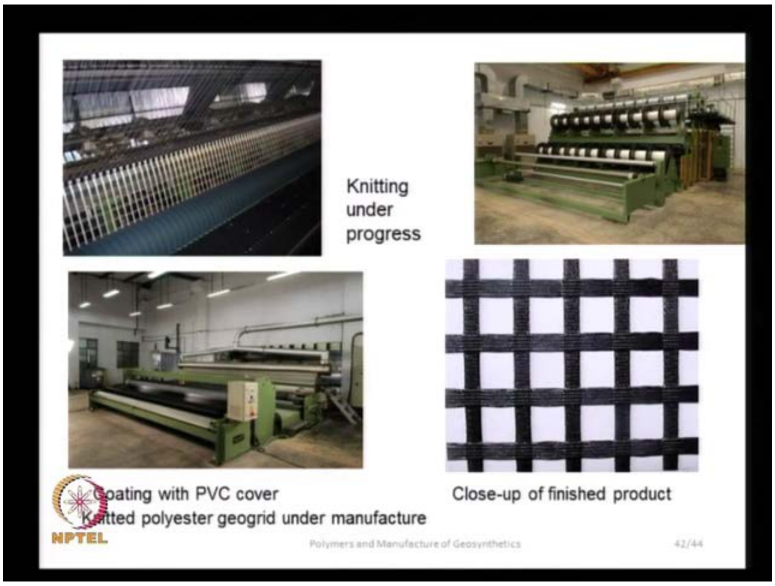

And here, we see some photographs of the manufacture of a knitted type of geogrid. Basically, we have the fibers that are knitted together in 2 different directions, the longitudinal and transverse directions the warp and wet directions and then here, we see this knitting process. And then finally, once the geogrid is knitted it is coated with some coating materials, basically to protect it against ultra violet light and to protect it against installation damage during the construction. And here on this bottom left you see the entire geogrid being covered with some P V C cover and the final product is shown on the bottom right hand side.

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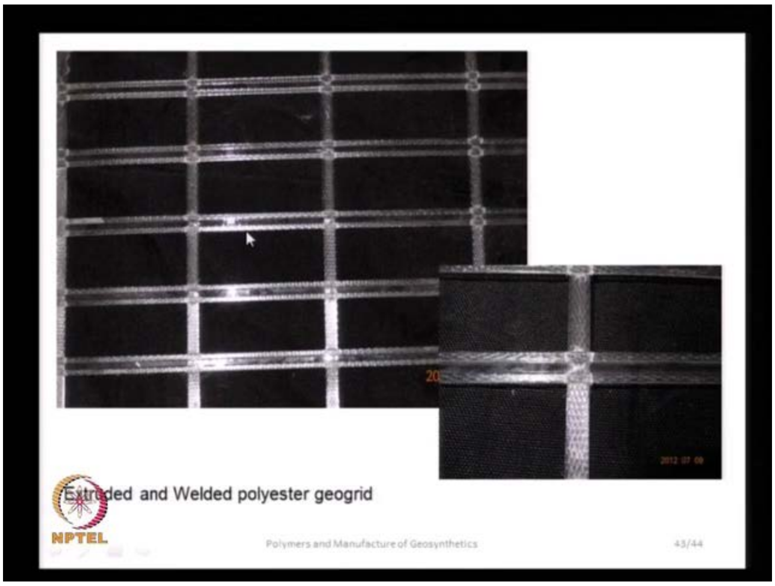

And some examples of the welded polyester geogrid is shown here, we take strips of this polyester strips and actually, these polyester strips, they are extruded. So, that they have good strength stiffness and long term stability and they are welded together at these junctions to fabricate this type of geogrid.

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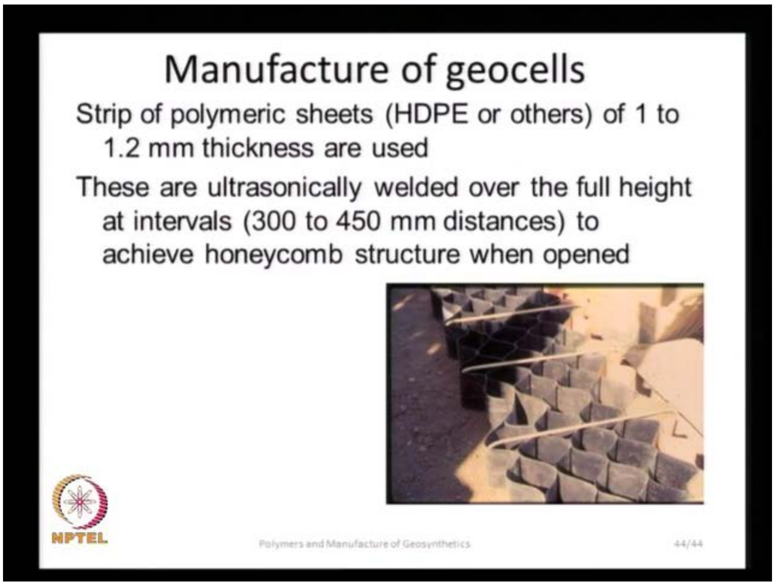

And the geocells, they are also manufacture by using plastic sheets usually H D P E sheets and some companies make out of polyester compounds, we take sheets of a 1 to 1.2 millimeters thick and they are laid along the length. And they are ultrasonically welded over the full height of the sheet at distances of 300 to 400 millimeters. So, that when this cells are opened up, we have a honeycomb type structure. So, basically the number of strips that, we take controls the number of the width that, we get for the geocells and the length of the strips that, controls the length of the geocells, that we get.

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So, basically here, we have seen the different types of polymers, that are used for manufacture of geosynthetics and a brief about the different types of manufacturing processes, that we used for manufacture of geotextiles and geogrids. And we have also seen, how to produce a geomembranes and geocells.

Thank you very much.