Manufacturing of turbines (gas, steam, hydro and wind)

Dr. Sunny Zafar

School of Mechanical and Materials Engineering

Indian Institute of Technology Mandi

Week - 06

Lecture 27

Welcome to this course on manufacturing of turbines. In this lesson 27 of this course, we will continue the discussion on material selection and details about the materials which are used in manufacturing of the wind turbines. So, the outline of this lecture will consist in detailed discussion on the polymers, the polymerization reaction through which the polymers are developed. The detailed discussion will also include the addition versus condensation polymerization. In general, we will discuss the thermal properties of polymers, the concept of glass transition temperature, heat distortion temperature. We will also look at comparison between how thermosets and thermoplastic they behave towards temperature.

And we will understand certain chemical structure of polymer matrices and how this chemical structure influences the properties of the matrices. So, polymerization is basically the reaction which is usually conducted at elevated temperatures and in this the high monomer concentration are utilized to improve the reaction efficiency. So this mixture can be cooled to stop the reaction when desired and once the desired chain length is achieved. It is also possible to quench the reaction by addition of end termination molecules and these molecules basically terminate the polymerization reaction.

And naming of the polymers is done by adding the word poly before the name of the respective monomer, for example, polypropylene. And the unique properties these polymers offer is because of the covalent bonding as shown here between the repeating units of the monomers which are highlighted using this block M. So, these covalent bonds they give the special properties to these polymeric chains which are long very long polymeric chains and because of this long structure of the polymeric chains, they always follow an amorphous mostly they follow the amorphous configuration while the polymer solidifies. So, unlike metals the randomly oriented structure of the solidified polymer chains gives a unique value unique values as well as characteristics to these materials. So, the polymerization reaction can take place by two routes so either of this route can be there but for different polymers the different routes are there so broadly these two routes are categorized as, addition and condensation polymerization.

So, addition polymerization this often results in relatively few but very long chain polymers. This is because of the low concentration of the initiating free radical which is used. Hence, only very few chains get initiated and highly reactive nature and rapidly growing chain steps the growth further. On the other hand, the condensation polymer, it usually results in few and shorter molecules. Many chains begin to condensate because two monomers can react to form new chains, thus creating large number of chains, each with competing for new monomers to add to it.

The length of the chain is usually characterized by the molecular weight of the polymer, which is basically a measure of how many monomers are present in the polymer chain. In general, it is observed for most of the polymers, the mechanical properties especially the stiffness, abrasion resistance, hardness, toughness, they increase with the molecular weight. And for composites, the thermal property and toughness in general are largely dependent on the molecular weight of the matrix. So, if we see the thermal properties of the polymer, so in this case we will look at the concept how of liquid and solid is applicable in polymers and how the forces of attraction at the molecular level they function in polymeric molecules. The temperature at which the molecules lock in place and that material becomes solid, it is known as the freezing point mass of the polymer molecules.

So, this greatly varies with the polymers and as mentioned earlier polymers are amorphous materials and there is no single sharply defined temperature which can be called as melting point or freezing point rather it is always a range of temperature in case of polymers. So, broadness of this freezing and melting point is especially true in this case as the molecule chain is very very long and at the same time these molecules also get entangled and randomly arranged. So, because of this polymers are also said to be amorphous materials. Upon heating what happens the vibration and rotational energy increase the lateral and transitional movements in the polymeric molecular chains. So, the melting point is directly proportional to the molecular weight.

What this means is if for a given polymer chain the molecular weight is on the higher side, so in this case the more energy will be needed to provide the heating for vibrational and rotational moments. So, for this the increased melting point will be observed for such polymer molecule chains. Decomposition point is on the other excrement while we heat the polymers. At decomposition, as the name itself is suggesting the decomposition temperature what happens once the polymer molecule chain reaches the decomposition temperature. The polymer has undergone sufficient heat input so that, the motion of the molecule is great enough means the energy exceeds and it is great enough to break the primary bonds between the monomer units.

So, at this stage we say the polymeric chain has decomposed and the monomer are free to move out. So, here we will see the concept how the small polymer chains and large polymer chains they vary. So, in case of small polymer chains as the molecular weight is less. So, there in this case the transition from solid to liquid will happen at a relatively lower temperature. compared to the large polymer chains where the temperature at which the melting or freezing takes place, this range occurs at a higher value.

And subsequent to that the decomposition point also increases with respect to the increase in molecular weight of the polymeric chain. So, we can see there is also a slight increase in the decomposition point here and because of which in case of the long polymer chains the decomposition point also becomes slightly higher. beyond the decomposition point be it the small polymer chain or the large polymer chain the charring and gases are generated. So, because of which the decomposition of the polymer is observed. So, next we look at the concept of the glass transition temperature in case of polymers.

So, glass transition temperature is one of the important fundamental temperature to be looked at from the perspective of the manufacturing of these polymer and related composites and as we know these composites are being used to manufacture the wind turbine blade. So, at the glass transition temperature a thermal transition occurs in the solid phase which marks a change from rigid solid to one which is more piliable. So, the motion of the atoms in the solid rigid solid below the glass transition temperature which is also denoted by T and with G in the subscript is generally simple vibrations in rigidly fixed positions. So, means in their mean position there are just simple vibrations and there is not much movement in the atoms. above the Tg what happens, but below the melting point, the vibration and rotation of the atoms becomes more expensive and atoms may be able to move over short lateral distances.

So, this short range movement of the atoms is still there. However, the atoms are still locked to their relatively fixed position and their continued entanglements. Hence, the temperature range between Tg that is the glass transition temperature and the melting point the material somewhat becomes fallible although it is solid and many a times the manufacturing for the manufacturing process, it is desired that the temperature range during manufacturing it should remain between the glass transition temperature and the melting temperature of the respective polymer. So, the mechanical properties of the polymers, they are also strongly dependent on the ambient temperature and loading rate. So, unlike metals, so the strain rate or the loading rate also decides the mechanical properties of the polymers.

And, if there is variation in the testing conditions or the service conditions, the values of the mechanical properties, they largely vary in case of polymers. Again, this is because of the energies being supplied to the long polymeric chains and the entanglement how it varies with respect to the temperature. So, at the glass transition temperature, what happens, the polymer which appears to be a very hard and brittle glass like material at the room temperature, once this material reaches the glass transition temperature, so it acts as a soft and tough material like leather. Over a temperature range around the glass transition temperature, the modulus of the material reduces by order of 5 orders of magnitude. And near this temperature, the material also renders a viscoelastic behavior.

The mechanical characteristics of polymer solid depend on ambient temperature relative to the glass transition temperature of the polymer. If ambient temperature is above the glass transition temperature, the polymer exhibits low surface hardness, low modulus, and high ductility, which is very favorable for molding applications or the manufacturing processes. So, here we can schematically see how the glass transition temperature varies and we can see the rotational and translational motion of the atoms is it sets into place beyond the glass transition temperature because of which, so there is a relative drop in the stiffness of the respective molecule. And of course, once we reach beyond the melting temperature. So, then there is a rapid drop in the stiffness and we enter the rubbery state.

So, this temperature zone where this transition of a hard solid, so here we can say it is solid brittle. So, these characteristics are there before the glass transition temperature hard. So, all these characteristics they change into soft, ductile, less hard sort of a material in the glass transition temperature range. So, identification of the glass transition temperature is very essential for any polymer before we decide the manufacturing route and also decide the service conditions of such polymer or the composites which are based out of such polymers. Next, we look at this concept of the heat distortion temperature.

So, heat distortion temperature or HDT it is basically the deflection temperature under load test. So, at which temperature the deflection of the polymer sample takes place. So, heat HDT is a very convenient way to estimate the maximum use temperature for the polymer. Because, as we know that polymers are amorphous materials. So, in that case, it is not possible to have a fixed temperature range.

Another challenge is because of this amorphous nature. So, you have a range of temperature over which the polymer is basically functioning or the polymer is melting. Secondly, the polymer mechanical properties are also dependent on the rate of loading. So, here the static load which is applied can also tell us at this particular static load what is the level of deflection being achieved at say some elevated temperature. And to achieve this, this type of a setup is used where we place the sample that is the composite or maybe the polymer sample here on these two supports.

In this sample, what happens the heating of this oil this is the media which is heated at a constant rate say 2 degrees per minute and a constant load is applied here and what happens as the load is constantly applied but, the temperature is increasing at the rate of 2 degrees per minute at a particular temperature value at a given fixed load we will observe the polymer sample has deflected and we can estimate the level of deflection or the amount of deflection. So, that particular temperature becomes the heat distortion temperature and that basically gives a end limit of the service temperature of that particular sample be it a polymer sample or the composite sample based out of similar polymers. So, this estimation of temperature is also important from the service conditions point of view. The glass transition temperature is important from the manufacturing processes selection point of view. So, next we come to detailed discussion on the different types of polymers which are primarily based either thermosets or thermoplastics.

So, as we know the interaction of the molecules is dependent on the intermolecular attraction between the polymer molecules and this has a major effect on the key properties of polymers. Interactive bonds between the polymers they are sometimes also known as cross links. They have approximately same strength as the bond between the atom and the atoms of the polymer molecule itself. So, based on this discussion the categorization of polymer is done in thermosets and thermoplastics. So, thermoplastics are basically solid at room temperature and they have no cross link present in them.

They are melted and softened by heating and molding once they reach the molten stage. Examples include injection molding, blow molding and thermoforming are being utilized in these type of manufacturing processes. Popular thermoplastics include polyethylene, polypropylene, nylon, polycarbonate, polyethyl tetraphylate, polyvinyl chloride, acrylic and acetyl. Service temperature of the thermoplastics, it needs to be considered because they become moldable or we can say plastic with increased temperature because absence of cross links can help them to get remolded upon reapplication of heat and pressure. So, we can see here comparison between the different types of thermoplastic and thermoset where in the thermoplastics we can see just the dangling bonds, secondary bonds from the primary polymer chain.

This is basically the primary polymer chain and these secondary bonds are dangling freely. But in case of thermosets, so there are no freely dangling secondary bonds, rather the crosslinks are developed depending on the curing conditions and the type of thermoset being used. And these crosslinks, they help to keep the long polymer chains or the primary polymer chains in place. And the cross links are basically irreversible bonds, once they are formed they cannot be broken by again applying heat or pressure. So, therefore, these thermosets they are able to retain their shape even at elevated temperature.

The only difference what will happen once you take it beyond the at an elevated temperature as you keep on increasing the temperature. So, what happens, instead of melting the thermoset it directly begins to char or burn. So, thermosets, they are usually liquid at room temperature. They are solidified into the desired shape by heating, which creates cross links between the polymer molecules. So, cross link, this changes the basic nature of the material.

Upon heating, as cross links are formed, material is said to be cured. Because of curing, thermosets cannot be remelted. Therefore, thermosets, they become fixed with heat. And manufacturing processes such as hand layup, compression molding, filament winding, resin transfer molding, pultrusion etc. are dependent on this property of the thermosets.

So, popular thermosets used in engineering application and products include polyester, vinylester, epoxy, polyamide, phenolic and cyanoacrylate. Upon formation of crosslinks now what happens the crosslink bonds they restrict further movement of the polymer molecules with the temperature even greater than the intermolecular attraction forces. So, in this regard the Tg increases with cross link. So, more heat is increased. So, as more heat is needed to increase the movement of molecules, the examination of Tg is often a preferred way to know the extent of the polymerization.

So, by estimating the value of the Tg that is the glass transition temperature. We can estimate how much quantity or how much percentage of the polymer has cured or how much is uncured. So, in case of this comparison upon crosslinking the molecular weight of the polymer molecule it increases to a so large value that the melting point increases beyond the decomposition range. So, that is why as the curing or the polymerization keeps on continuing and more and more cross links are developed the polymeric chain becomes so long and so entangled with more and more monomers added. So, the value of the melting point it exceeds beyond the decomposition range and as temperature increases before the melting is witnessed the polymer it decomposes.

Therefore, charring is directly observed in case of the thermosets and melting is not observed. So, in terms of the role of temperature, how the temperature influences the viscosity of these thermosets and thermoplastics. So, in this case the thermoplastics are much straightforward because they are solid at room temperature as just we discussed and because of absence of any cross link bonds with increase in temperature the viscosity of these thermoplastics upon melting is keeps on reducing and it reduces further. But what happens with thermosets? So thermosets, they behave in a much different way compared to thermoplastics. In this case, they are obviously liquid at room temperature.

But as the temperature starts to increase, the viscosity reduces, which increase the mobility of the atoms. But, once the temperature reaches the curing temperature of the respective thermoset, So, then the cross link bonds begin to form. So, in this case as the cross links begin to form, so we reach a point where the movement of the polymeric chains, it starts to restrict and then the behavior of the thermoset it changes from a liquid to a gel type of a state which we known as the gelation point. And as the heating is further continued more and more crosslinks are developed because of which the solid sort of a you know state is achieved in the respective thermoset. And because of the solid now the viscosity it suddenly reduces.

And, upon this the viscosity suddenly increases as the solid state is achieved. So, in this case as the curing further continues the viscosity keeps on increasing more and more because of which we observe a solidified material after the curing of thermoset. And it is opposite in case of thermoplastic with increase in temperature absence of cross links they render reduced viscosity and we end up with a liquid type of a material in the end. So, if we compare both of the thermoplastics and thermosets from the viscosity standpoint comparison. So, on the graph that we just discussed the thermoplastic with initial viscosity above the solid liquid line known as the solid at room temperature.

As the temperature increases the viscosity reduces due to the motion of molecules. This leads to melting and viscosity drop below the solid-liquid line but as crosslinks are absent in thermoplastics at any point of time if the temperature is reversed the viscosity will increase. So, this was perhaps shown by this double-headed arrow in case of thermoplastic. So, it can go both ways if we reduce or increase temperature. For the thermoset, the initial viscosity is just below the solid-liquid line.

As the temperature increases, the viscosity drops and thermosets due to lower initial molecular weight because once the cross-links are absent, the molecular weight is less. It reaches to a minimum, then it rapidly increases substantially above the solid-liquid line and two separate phenomena occur, so thermoset thinning and gelation. So, thinning occurs as the viscosity is reducing and gelation occurs as the viscosity increases. So, next we look at the structure of some of the aromatic molecules used in the thermosets which are widely used in manufacturing of the wind turbine blades. Where, we can see this closed ring type of structure in the phenol which is having phenolic type of thermosets having the three-dimensional structure even in epoxy such structures are present.

So, such structure render enhanced cross-linking because of which the strong bonding between polymer molecules is observed upon curing. So, in case of chemical structure the aromatic groups they are characterized by the presence of the benzene ring which significantly contribute to the polymer properties. So, benzene ring is basically a stable planar structure which enhance the polymer physical properties when incorporated into the polymer matrix. So, presence of the aromatic group it enhances the high stability of the polymer with resistance to chemical degradation. Aromatic structure, they also provide the overall rigid nature which provides overall stiffness and strength to the polymer.

The aromatic structure present in the polymer also has the pronounced properties and they also become in different configurations maybe like a pendant or maybe a backbone in specific arrangement. Polymers that lack the aromatic groups are classified as aliphatic meaning they do not contain the planar ring structure and thus may exhibit different properties compared to the aromatic counterparts. So, here we can see some other properties of the various matrix materials in the non-reinforced state which are used in many of the polymer composites and especially the thermosets which are widely used for wind turbine blade manufacturing. So, all the properties we can see with respect to maximum use temperature, flexural strength, flexural modulus, density, tensile strength, tensile modulus, impact strength, moisture absorption capability, elongation and coefficient of thermal expansion.

So, with this we come to the end of this lesson. We will summarize what all topics are covered. So, in this lesson we have seen in detail the comparison of the addition polymerization versus condensation polymerization. We have looked in detail the concept of the glass transition temperature, Tg. We have also looked at heat deflection temperature. We have also looked at how the behavior of thermoplastics is different than behavior of thermosets.

And lastly, we have looked at the chemical structure of some of the popular thermosets used especially in case of wind turbine blade manufacturing. So, in the next lesson, we will see more properties on the matrices as they form the base for the manufacturing process for the wind turbine blades. Thank you.