Manufacturing Processes - 1
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Module - 01
Lecture - 04
Metal Forming – Fundamentals

Very good morning to all of you. I welcome you to the second session on metal forming processes. This session will be dedicated towards all the processes, which come under the broad specialization of metal forming. So, first session we had 3 lectures, in those 3 lectures we discussed regarding the powder metallurgy. Now, in this second session that will be cover that will be overall covering 9 lectures, in these 9 lectures we will go through the various aspects of metal forming.

Now, metal forming is one of the important manufacturing processes, as we might have seen when we go to the market or we go to some manufacturing industry. We see that the metal is being formed into different shape, as we do sometimes if you take a hammer and start hitting a metal piece. We will, we can see that under the impact of the hammer or the forces that we can apply with the help of a hammer, the shape of the metal can be changed. So, the basic principle of metal forming is that by the application of force, the metal is plastically deformed.

So, in this session or in this lecture, we will discuss regarding the metal forming fundamentals, and in the subsequent lectures during this particular course on metal forming. We will see that, what are the different types of metal forming processes? What are the various numerical formulations? And what are the basic process details of metal forming processes? So today, we will start with the very fundamentals of metal forming.
As we go through this lecture, we will see what are the basic manufacturing processes? Where does metal forming fit into the manufacturing processes, then what are the basic principles of metal forming? What are the various metal forming processes? Then we will go and discuss regarding the hot working and cold working of metals. So, in order to start, let us first understand what are the various basic manufacturing processes? So, the basic manufacturing processes as we have earlier also seen in powder metallurgy, that there are 5 different types of basic manufacturing processes.

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These manufacturing processes are casting, deformation processes or metal forming processes, machining, joining. In joining we include fastening, welding and adhesive joining, then we come on to the finishing operation. Now, all these processes are used to convert a raw material into a final product, we have certain raw material the material can be cast iron, it can be steel or it can be any other form, it can be plastic, it can be any kind of wood. So, any raw material is converted into the final product using any of these basic processes.

So, we have already discussed in the basic lecture on powder metallurgy, that casting can be either it can be done using expandable moulds or it can be done using permanent moulds. Similarly, deformation processes we have already seen, rolling, forging, extrusion are some of the deformation processes, which are used to convert the basic raw material. The basic raw material, in case of this deformation processes can be it can either be a bar of material, it can be a rod, it can be a sheet metal, it can be a plate.

So, all these type of materials or the raw materials using any of the deformation processes will be converted from it is raw form to it is final form, that is in the form of a product. Then coming on to machining, in machining already we have seen the material is removed in the form of chips the chips maybe of different type, it can be continuous chips, it can be discontinuous chips or it can be the discontinuous or continuous chips with the built up edge. Then we come on to the joining processes, joining processes either can be permanent joining processes or these can be temporary joining processes. Under joining we have a fastening, welding and adhesive joining. Now, welding whenever we do we make a permanent joint, wherever we make use of a fastening, we make use of a temporary joint with the help of nuts and bolts. Then, why finishing processes are required, already we have discussed again just to give a brief summary, if we require a very good surface finish or we require some surface characteristics, some anti wear coatings then we go for the finishing operations.

Different finishing operations are grinding, lapping, horning, super finishing. So, there are different types of finishing operations, which can be used to impart the surface characteristics to the product. Now, as we see, we convert a raw material from it is raw form into the final product form. So, there are number of processes which can be used to do this job.

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So, the job basically is to convert a raw material into the final product, but the problem arise is that there are a number of a manufacturing processes out of which we have to choose that, which manufacturing process we should use to convert the raw material into the final product. So, selection of a manufacturing process to produce a product is a trade off among a number of variables. So, what are these variables? These variables are material of we can say material of the product that we are going to produce, it can be wood, it can be stainless steel, it can be cast iron, it can be aluminum, it can be titanium. Now, the material will play a important part in selection of a manufacturing process. The second is shape, size, complexity, volume and there are many others factors which may which we may have to consider, in order to finally select a manufacturing process. So, already starting with the first, I have told the material plays a very important role in the selection of a manufacturing process. There are like, the metal forming process cannot be used for brittle material, because if brittle material we strike it with a hammer or we subject it to a combination of different forces, the brittle material may fail under the impact of forces.

Similarly, all the materials are not castable, all the materials are not machinable. So, depending upon the material we have to see, whether we are going to cast it or we are going to machine it or we can use any of the basic process of metal forming to convert that material from a raw material into it is final form. Coming on to the shape, the shape also plays a very important roll. Now, if we want to make a very big product, it can be made using the sand casting process, but if we choose a permanent dye casting process, where the size of the dye will be a limitation.

Moreover, if we want to finish a very large size of a product or a very large size, then we have to put it on a machine. Now, if we put the big size of a product on a machine, it will be very, very difficult for the machine to handle a very big product. As we have seen or we can see that the limitation of the machine is the size of the bed or the size of the job it can hold. So, in order to machine a very big product, we need to have a very big machine, so which may not be a feasible or a viable operation. So, size of the product is also an important criterion for selecting a manufacturing process.

Similarly, the shape of the product is also very, very important. Now, in powder metallurgy we have seen that if the shape is very, very intricate. The powder may not flow into the intricate parts of the dye, and we may not get the product according to the desired quality. Moreover, if the shape is very, very complex, then we may not be able to make it using a dye casting process. We may use a split type of a pattern and different types of molding procedures to make it by a sand casting or there can be other processes to make it.

So, the size as well as the shape of the product will define, that what type of a manufacturing process, we should select for converting that particular material from a raw stage to the final stage. Similarly, the complexity in the operation also plays a important role, then coming on to the volume. Now, the volume of production is also very, very important, as we can see that in sand casting, we can always we have to make a mould, because it is expandable mold type of casting.

So, when we have to make number of times the mold, the procedure will be time consuming, as well as the lead time will be more. Wherever in permanent dye casting operation, there is a permanent dye, the metal is injected into the dye in the molten stage and we get the final product. So, the volume or the production rate is extremely good in case of permanent dye casting, whereas it may be comparatively less in case of sand casting.

Similarly, there are other processes which may be have which may producing the products at a very faster phase, as compared to the other processes which maybe converting the raw material into the final product at a very slow phase. So, the selection of a particular manufacturing process to convert a raw material into a final product depends upon different factors. The factors, the broad factors are the major factors are material, shape of the product, size of the product, complexity and the volume. Already it is mentioned, there are many other factors which will affect the selection of a manufacturing process.

So, till now we have seen that in order to convert a raw material to final product, we have different options, different manufacturing processes are there and depending upon certain variables. We have to make a trade off among all these manufacturing processes, to decide that which manufacturing process is going to be used for converting raw material into it is final form. So, in these series of lectures, we are dedicating our self towards two important aspects of manufacturing that is powder metallurgy, as well as the metal forming operations.

So, we already have discussed 3 lectures on powder metallurgy, the next 9 lectures will be dedicated to metal forming operation. So today, we are going to start with metal forming fundamentals. Now, deformation processes, as we can see if we want to the change the shape of a metal we can hammer it, we can apply some forces and it will convert into the shape that we want. Moreover, if there is a rod of a bigger diameter, and we want to change it into a wire of smaller diameter. We can use a dye, we can pass the rod through the dye and in the subsequent steps, we can convert from a larger diameter to a smaller diameter.

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So, there are different types of deformation processes that are there. So, what are basically deformation processes? Deformation processes exploit a remarkable property of metals, what is this remarkable property which is their ability to flow plastically in the solid state without deterioration of their properties? Now, the metals have this property that they can flow plastically without deformation, and without substantial change in their property. So, these deformation processes will make use of this property of the metal.

With the application of suitable pressures, as a simple example I have mentioned as the blacksmith or we can see a jeweler, he also give the shape to the gold and the blacksmith gives the shape to the iron or any particular material by hammering it. So, with the application of suitable pressure, the material is moved to obtain the desired shape with almost no wastage, almost no wastage this is an important point to address in case of deformation processes.

As we have seen, different manufacturing processes machining removes the material in the form of chips, and then gives us the final shape. In case of deformation processes, we are not going to remove any material, it is only the changing in shape of the material with the application of suitable pressures. So, with the application of the suitable pressures, the material is moved to obtain the desired shape with almost no wastage.

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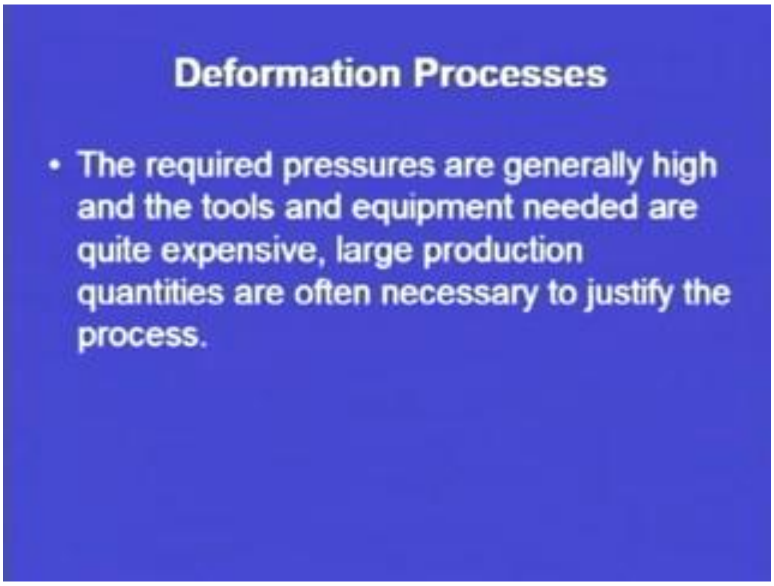

The required pressures are generally high and the tools and equipment needed are quite expensive, large production quantities are often necessary to justify the process. Now, the equipment, in case of metal forming or the metal forming processes are extremely of high rate. So, it is not that all the equipment or all the processes incur very high cost, there are certain processes like when we forge with the help of a hand or hand forging the process is not that expensive, but wherever we go for dye arrangement or punch arrangement.

So, the material of the dye, the size of the dye, the intricacy of the product often necessitates that we need to have a very good dye, so that whatever is the shape of the dye. Whatever is the surface finish on the inner walls of the dye is replicated on the final product. So, the dye wall or the lining of the dye wall or the size of the dye often results in a high cost. So, this high cost can only be justified with the large production volume.

So, if the production volume is substantially large, then the initial cost of establishing or the initial cost of setting the process will be spread over a number of products, but if the production volume is substantially less or it is comparatively less. Then, whatever cost we have incurred on setting up of the machinery or the setting up of the machines will be distributed only on small volume of components. So, the cost of the components will be extremely high.

So, in order to justify the high cost of establishing or the high cost of setting up of a metal forming plant, we should be able to justify it in the cost wise. So, the cost should be comparatively or the cost should be justified with the large production volume. Now, as we have seen that the metal is pressed under suitable pressures, and we get the desired shape. So, when we press the metal, the metal undergoes different types of stresses.

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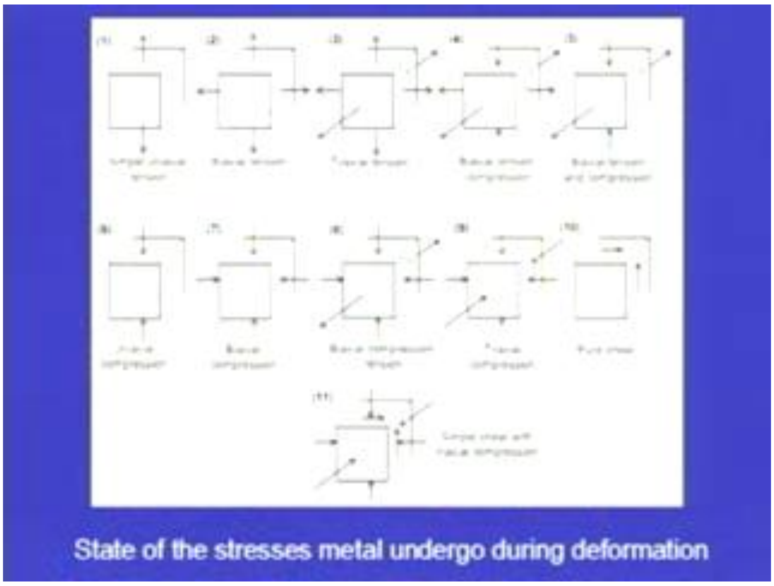

So, this diagram shows that what are the different types of stresses, a block of metal can undergo. So, we can see that either we can have simple uni axial tension or we can have biaxial tension, we can have tri axial tension. Then, we can have biaxial tension and compression, a combination of tension and compression we can have. Then, we can have biaxial tension and compression, then we can have uni axial tension. We can have biaxial compression, we can have biaxial compression as well as tension. So, we can have two axis we can have compression, and then we can have tension also.

Tri axial compression can be there, we can have poor shear, we can have simple shear with tri axial compression. So, in here the point to mention is that whenever we go for a tensile testing or the material is subjected to tensile load, we see that the material fails, after the necking has started. We fix one end and then we pull the other end, and in between there is a necking reason which develops, after the necking reason the material fails. Whenever we apply a compressive force, we have a suppose we have a rod like a specimen, then we will apply a compressive force.

And if the slenderness ratio or the spect ratio is not suitable, then it will buckle under the applied compressive loads. So, buckling will be the limiting factor for compressive loads, and necking will be the limiting factor for deformation under tensile loads. So, either the material will fail after the necking or the material will fail after the buckling. Another case to be studied here is that if there is a rod, and neither we are compressing it nor we are applying tensile loads, but we are just rotating it.

So, when we are rotating it or we are subjecting it to a shear load like this, then under the shear load it may fracture. So, there is a limit to the deformation, it is not that if we take a metal, we can elongate it to as much as length as possible or we can compress it to as much as possible, there are limits to elongation as well as compression. Similarly, there is a limit to the torsion also, so what are these limits. These limits basically are, necking, buckling, as well as fracturing.

So, whenever the necking starts the material is going to fail, whenever the buckling takes place we are not going to get the desired shape of the product, that we have designed the process for. Similarly, whenever fracturing takes place, the material is going to fail. So, there is a limit to the deformation, and there are limiting factors up to which the deformation can take place. So, these are certain states of stress that metal undergo during the deformation process.

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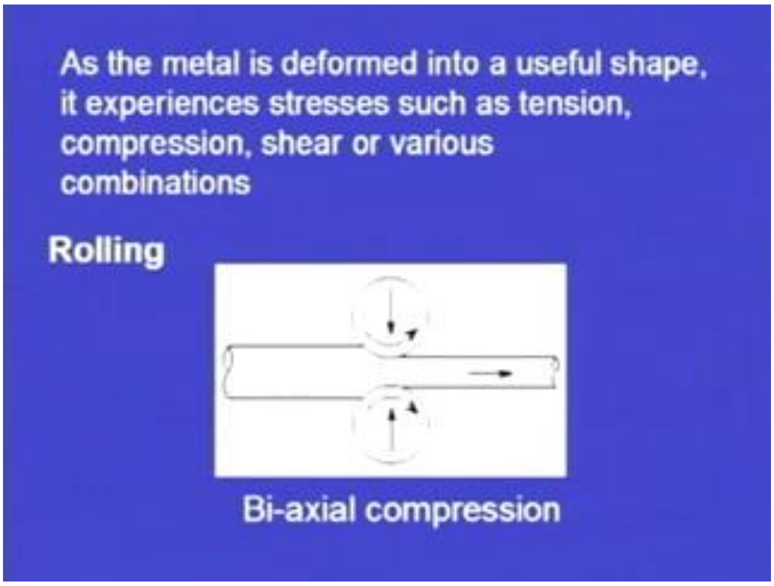

Now, as the metal is deformed into a useful shape, it experiences stresses such as tension, compression, shear or various combinations. So, as we have seen in the previous slide, there are different types of combination of stresses that are possible, their states of stress that the metals undergo during deformation, we have already seen. So now, as the metal is deformed into a useful shape, it experiences stresses such as tension. It can undergo compression, shear or various combinations like we have seen biaxial tension, biaxial compression or it can undergo a combination of these types of stresses.

Now, there are different types of processes that are possible using this state of stresses. Now, the metal will undergo this type of state of stresses under different types of operations. Now, we will under, we will see that what are the different types of operations? And under what operation the metal undergoes? What type of states of stress? Now, the first operation is rolling, now what is the rolling operation?

In rolling operation there are two rolls or there can be four rolls, it depends upon the type of mechanism that we have chosen for rolling operation. So here, the diagram that is shown here, there are two rolls which are rotating, and which also have the center distance which has been fixed, depending upon the final dimensions of the shape that we want to make. So, we can see that there is a bigger rod that is going inside, and there is a smaller rod that is coming outside.

So, what type of stresses are prevalent here, the stresses are biaxial compression. The metal is being compressed from two sides or it is undergoing compression that is biaxial. So, in rolling process, where we are reducing the cross section of the raw material, and we are getting the desired cross section after the rolling. So, the metal has a state of stress that is biaxial compression.

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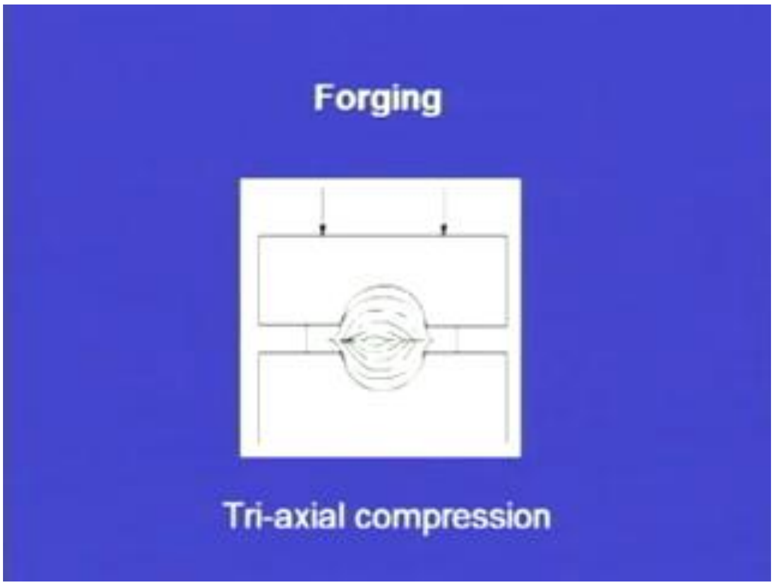

Similarly, there are other metal forming operations like forging. Now, this diagram shows the forging operation, now what is the forging? Already one example I have told, whenever we take a metal either in the hot or in the cold condition, and hammer it then that process basically is called forging. Now, forging can be hand forging or we can use different type of presses to change the shape of the metal into the desired form. So, forging operation basically has tri axial type of compression stresses. So, there are three axes or tri axial means from three sides, where it will have compressive force, compressive stresses.

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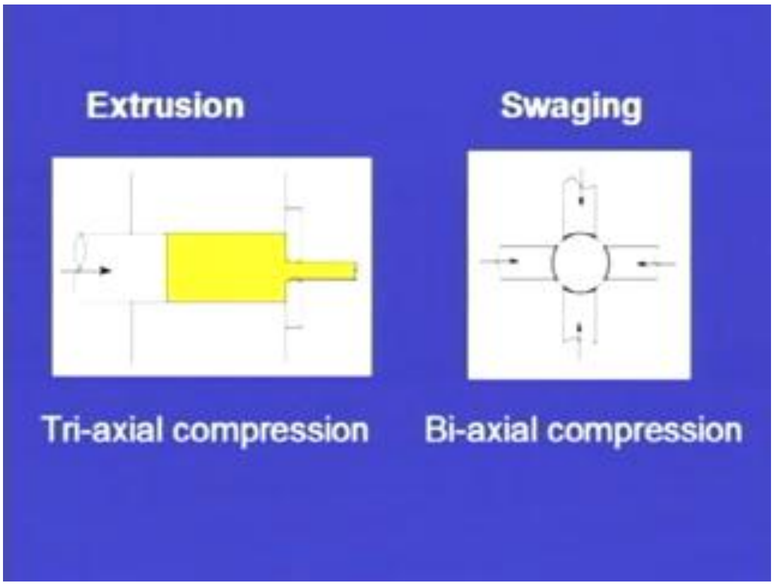

Now, we will see different types of other processes, we have already seen two processes, where first one was rolling and second one was forging. Now, we come on to the third process that is extrusion, what is the basic extrusion process? In basic extrusion process this is the metal, the metal is pressed from this side and this the dye opening. Now, dye opening decides the shape of the metal or the shape of the final product that we want to make. Now, if you want to make a rod this will have a circular cross section.

Now, depending upon the opening of the dye, we will get the desired output. So, the metal here if pressed form this side and it comes out of the opening. Now, this can very easily be correlated to our morning process of brushing our teeth, whenever we go and brush our teeth, we take out at we take a tube and we press it from one side and the tooth paste comes out from the other side. Similarly, in this process we press the metal here, and it comes out through the opening or the aperture or the dye here.

So when, whenever the metal is pressed we get a final product. So, the final product or the shape depends up on the dye opening. So, what type of stresses are present here it is the tri axial compressive stresses. So basically, this extrusion processes can be of two types, either it can be forward extrusion or it can be backward extrusion. In case of forward extrusion, we push the metal from this side and the metal comes out from the opposite side like here. In case of backward extrusion, there is a opening at this particular section, and the opening decides the shape that we want to make.

So, we will pressurize the metal or we will apply pressure from this side, and the metal instead of coming out from this side will be coming out through the opening in this direction. So, basically, the extrusion has two different categories, the first one is the forward extrusion and the second one is the backward extrusion. Similarly, the another process or the metal forming process swaging, in swaging the different types of stresses are biaxial compressive stresses. So, different states of stresses are prevalent under different manufacturing operation, that fall under the category of metal forming operation.

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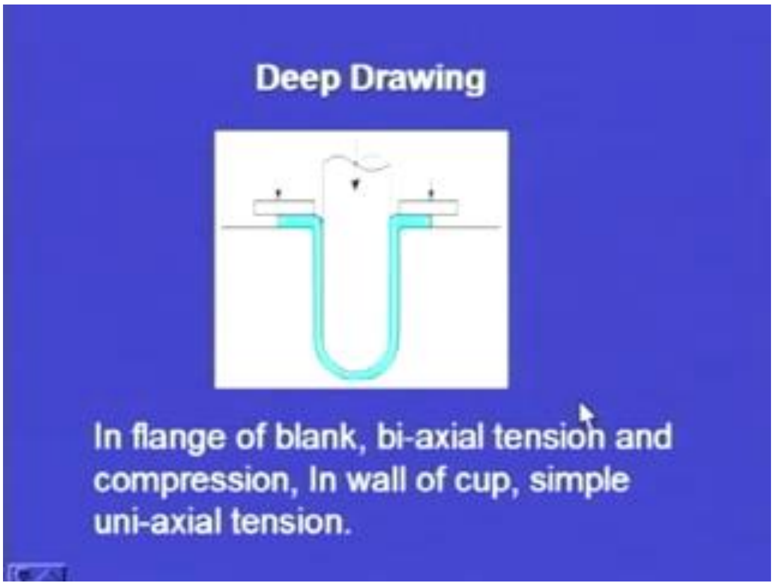

Now, deep drawing is another metal forming operation, in case of deep drawing we see this the shape that is being drawn, the color of the metal is shown here. This colored portion in showing the metal, which is being deep drawn, and this is the punch which is drawing the metal down. So, in case of deep drawing, we make different types of shape of sheet metal using the process of deep drawing. In case of deep drawing in flange of the blank, biaxial tension is prevalent and in flange of blank biaxial tension and compression is prevalent. In wall of the cup simple uni axial tension is there.

So, we can see the state of stress depends upon the shape or the final shape of the product that we are making. In certain sections, the state of stress will be different, and in certain sections the state of stress will be different. So, in case of deep drawing, we can see that in flange of the blank bi axial tension and compression is present. And, in wall of the cup, simple uni axial tension is present. So, deep drawing is another operation for another metal forming operation, which is use to convert a sheet metal into the desired shape of the final product.

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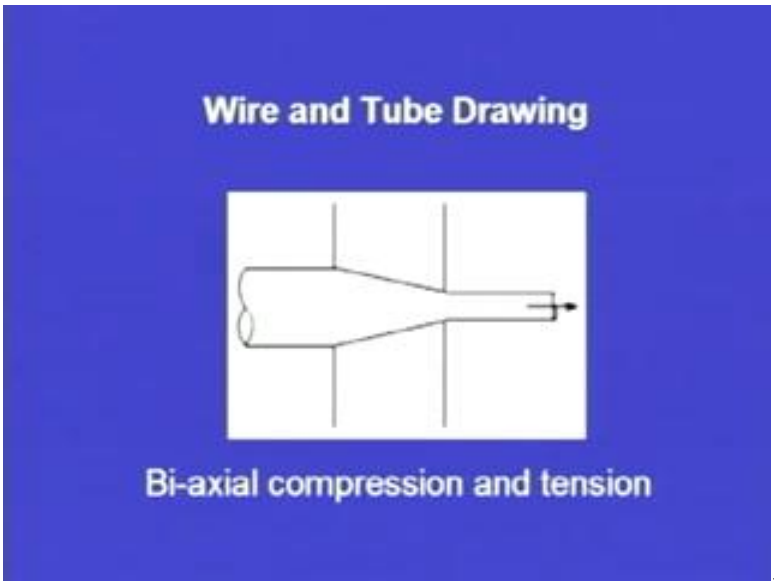

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Now, already I have told if we want to reduce the cross section of a particular rod, then we can use wire drawing or tube drawing. So, wire drawing or tube drawing can be done, where we can see the pressure or the load or the force is applied at this angle, not at this angle, but at this end of the work piece. And we are pulling the material through the dye opening. So, in case of wire drawing and tube drawing, biaxial compression and tension is present. So, we can see there are different types of states of stresses, a combination of state of stresses which are prevalent, whenever a material is deformed plastically under the applied pressures or the applied loads to convert it from one shape into the another shape.

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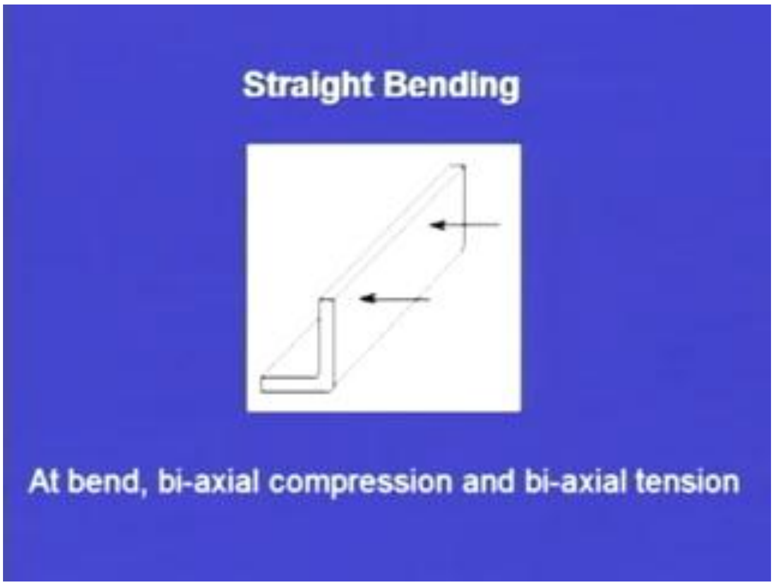

Now, in case of straight bending the straight bending we can see the load is applied, the arrows show in the direction in which the load is applied. So, at the bend, bi axial compression and bi axial tension are present. So, we have seen different types of metal forming operations starting from rolling, forging, then we have seen different types of deep drawing operations, tube drawing, wire drawing, state bending.

So, there are different metal forming operations, which are used to change the shape of the metal. And during this change of shape of metal, the metal undergoes different types of state of stresses, which have been shown. So, different processes undergo different types of state of stresses. So, we have seen that straight bending for example undergoes bi axial compression and bi axial tension.

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So, all these processes are basically undergoing the process of plastic deformation. So, in plastic deformation in metal helps to convert the shape, former raw material in to the final form, so what basically, now we will go through what happens during the plastic deformation of metals. In plastic deformation in metals, metals basically all of us know these are crystalline in nature, and these consist of irregularly shaped grains of various sizes. So, crystalline materials are made up different types of grains, which have irregular shape.

Each grain is made up of atoms in an orderly arrangement known as a lattice. So, grain further is made up of atoms, which have an orderly arrangement and this orderly arrangement is known as a lattice. Now, the orientation of atoms in a grain is uniform, but differs in adjacent grains. Now, within a grain if we see the atoms are arranged in a oriented manner or they have a particular orientation, but in adjacent grains the orientation of the atoms may not be same. And the orientation is usually different in adjacent grains.

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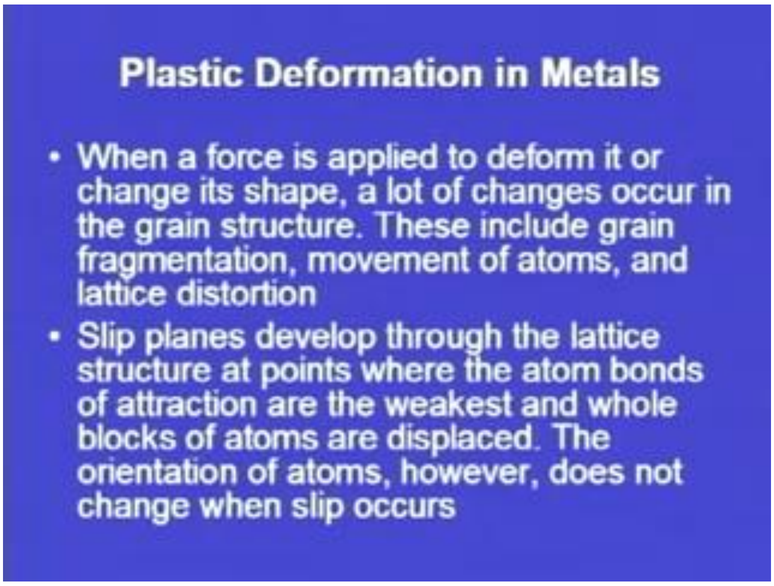

Now, as we have seen the basic structure of a metal it is crystalline, it is made up of grains, and orderly arrangement of grains that is called a lattice. We can once again see, the orderly metals are crystalline in nature and consist of irregularly shaped grains of various sizes. Each grain is made up of atoms in an orderly arrangement known as a lattice. And then, the orientation of the atoms in different grains will have different orientations, where they are not uniform the orientation is not same for all the grains.

Now, the basic metals how they are made up of there are different grains. Now, how that plastic deformation takes place, now when a force is applied to deform it or to change it is shape, a lot of changes occur in the grains structure. These include grain fragmentation, movement of atoms and lattice distortion. So, whenever a force is applied to deform it order to change the shape of the metal, different types of changes will take place in the grain structure of the metal. So, what will happen either the grains will fragment or there will be movement of atoms or there will be lattice distortion?

So, all these will aid in the plastic deformation of the metal. Now, slip planes develop through the lattice structure at points, where the atom bonds of attraction are the weakest. Now, slip planes will be formed, wherever the bond of attraction between the atoms is weakest or the atom bonds of attraction are the weakest. And whole blocks of atoms are displaced. So, we see, whenever we change a shape of a metal, the shape is like this, we bend it like this. So, the shape is changing from straight we are making a bend like this, we are making a l type of section.

So, physically we can see there the shape is changing, but what is happening within the metal what we should understand. So, there are formations of slip planes that develop through the lattice structure at points, where the atom bonds are the weakest, and whole block of atoms are displaced. The orientation of atoms however does not change when slip occurs, so the orientation of atoms will remain same.

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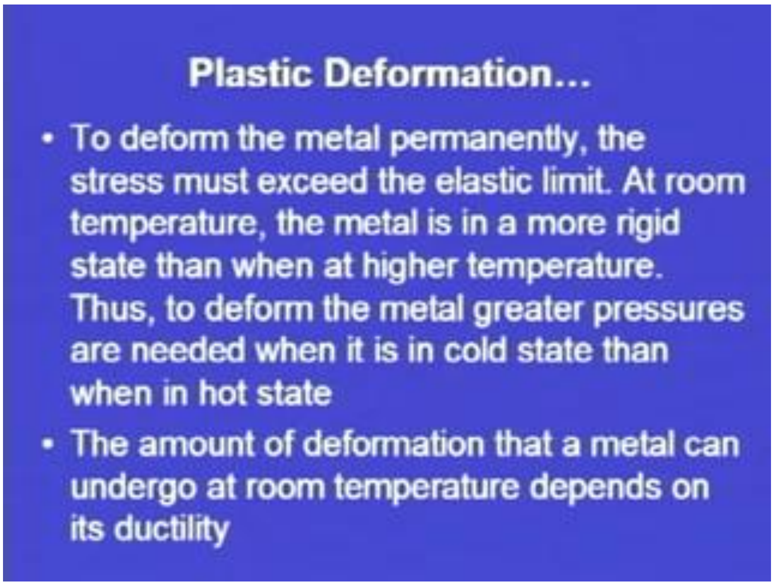

Now, in order to deform the metal permanently, the stress must exceed the elastic limit. As we have seen that already I have quoted, whenever we take a metal, we stress it under the loading or we apply a load or we apply the tensile type of loading on a piece of metal, the metal will stretch and a neck formation will take place. So, if we plot this process on a piece of paper that we call as the stress strain curve. So, this stress strain curve will give us the elastic limit, after which the metal will plastically deform.

So, to deform a metal permanently, the stress must exceed the elastic limit. At room temperature, the metal is in a more rigid state, then when at a higher temperature. So, it is easier to deform a metal in a hot stage, then in a cold stage. Thus, to deform the metal greater pressures are needed when it is in a cold stage, when as compared to when metal is in a hot state. So, this difference between hot state and cold state, we are going to discuss in detail. And this is a difference between hot working of metals and a cold working of metals, what are the advantages of hot working? What are the limitations of hot working? What are the advantages of cold working? What are the disadvantages of cold working?

So, advantages limitations of hot working and cold working, we are going to see in detail. So, it is easier to work a metal in a hot state, and more pressures are required when we are working with a metal in a cold state. So, it is easier to work in a hot state, but more pressures are required when we need to work in a cold state. So the amount of deformation that a metal can undergo at room temperature depends upon it is ductility.

So, it depends if a metal is ductile, it can undergo certain amount of plastic deformation. If a metal is not ductile, if it is brittle then it will not undergo that much amount of deformation and it may deform slightly, and after that it will have a brittle fracture. So, it depends upon the property of ductility that how much deformation is going to take place for a metal. Now, now we are going to address another important point that is strain hardening, so what basically is strain hardening.

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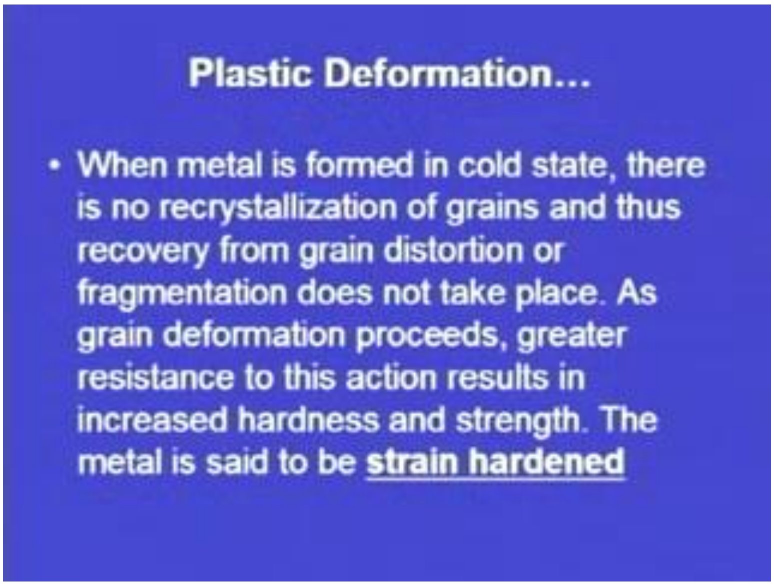

Whenever a metal is formed in a cold state, so we are talking about cold working here, there is no recrystallization of grains. So, the grains will not recrystallize, because we are not raising the temperature there is a recrystallization temperature, above which the process of recrystallization will take place. If we are working in a cold state we are working below the temperature, and there are the process of recrystallization is not going to take place. So, whenever a metal is formed in a cold state, there is no recrystallization of grains, and thus recovery from grain distortion or fragmentation.

Already we have seen, when metal deformation takes place, grain fragmentation is one of the common phenomenon. So, grain distortion or the grain fragmentation does not take place while in cold working, as grain deformation proceeds, greater resistance to this action results in increased hardness and strength. The metal is said to be strain hardened. So, hardness and strength increases, and the metal is said to be strain hardened. So, when the grain distortion or grain fragmentation is not taking place in the cold state, the metal may get strain hardened.

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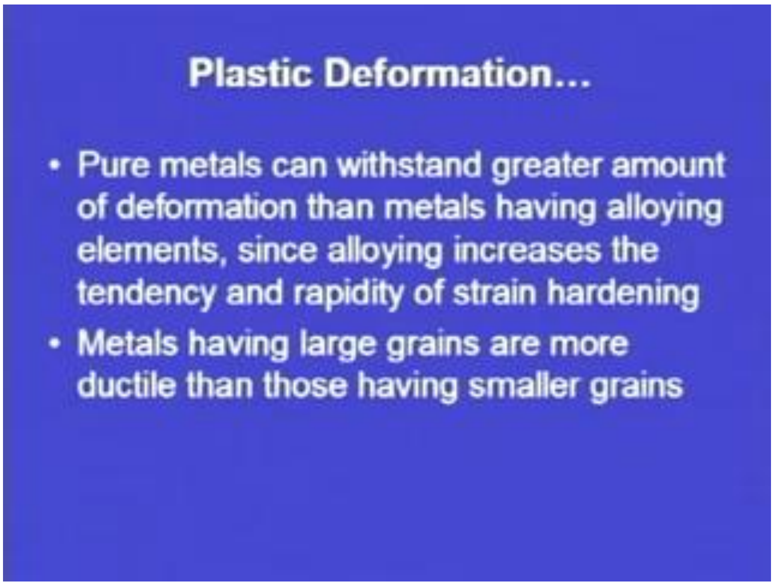

So, different types of metals and alloys will undergo different types of plastic deformation. So, pure metals can withstand greater amount of deformation, then metals having alloying elements, why? Because, alloying elements increases the tendency and rapidity of strain hardening. So, whenever we are adding a alloying element to the pure metal, then there are chances of strain hardening and the plastic deformation may be less. So, metal having larger grains are more ductile as compared to metals having smaller grains. So, we have seen that how plastic deformation takes place formation of slip grains, grain fragmentation, grain distortion. And then, depending upon the type of the material, if it is pure metal then it can undergo greater amount of plastic deformation. If alloying elements are added, then the plastic deformation may not be that much. Then we have seen that if metals have courser grain size or the grains are larger, then they are more ductile.

And if the grains are smaller in size, then the ductility will be comparatively less. So, plastic deformation, we are subjecting a metal to be a metal is subjected to plastic deformation, and then we are converting it from a raw material to a final product. Now, as we have seen that it is easier to work, when the metal is in a hot condition, and we need greater amount of pressures when the metal is in a cold state or a cold position.

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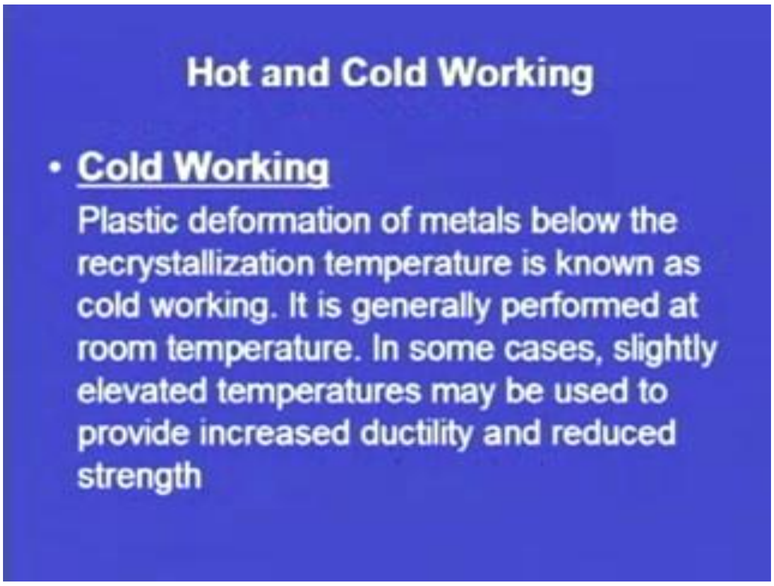

So now, we will briefly see that what are the hot and cold workings of metal? So, basically starting with cold working, what is cold working? Cold working basically is plastic deformation of metal, below the recrystallization temperature. So, the plastic deformation is taking place no doubt, but it is taking place below the recrystallization temperature. So, as we have seen that recrystallization or the grains are not distorting and too much of fragmentation is not taking place, it is below the recrystallization temperature.

So, it is generally performed at room temperature, so we are not heating the metal to a elevated temperature, it is generally performed at the room temperature. In some cases, slightly elevated temperatures may be used to provide increased ductility and reduced strength. As we have seen that whenever we heat the metal, it becomes ductile as well as the strength also reduces.

So, if under certain circumstances we need to work on a metal, whose ductility is not up to the desired level. We may slightly increase the temperature of the metal, but it will never go beyond the recrystallization temperature, slight increase in temperature is possible, but it will not increase the recrystallization limit.

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Now, cold working in comparison with hot working, there are certain advantages of cold working. Now, as we have seen basic manufacturing process, now selection of a basic manufacturing process to convert a raw material into a final product is a trade off, and the trade off is among different variables that are material, size, shape or it can be complexity or the volume of production.

Similarly, when we are deforming a metal whenever from those broad category, where we have five different basic manufacturing processes, we come on to another a simple category or a sub category of basic manufacturing processes that is deformation processes. Now, within deformation processes, we can either go for a cold forming operations or we can go for a hot forming or we can in other words, we can say either we can hot work the metals or we can cold work the metals.

Now, depending upon different advantages and limitations, we have to make a decision, either we have to go for hot working or we have to go for cold working. So, there are relative advantages and limitations, and depending upon the final specifications of the product that we are going to make. We will choose either of the tool, either we will go for hot working or we will go for cold working. Now, hot working in comparison to cold working has certain advantages, it has certain limitations.

Similarly, as we have seen in comparison with hot working, the advantages of cold working or the first one being no heating is required. So whenever, we have to change the shape of a metal using hot working or cold working operations, we have been either heated or we have to work at the room temperature. So, in cold working, we are going to work at the room temperature. So, no heating of the metal is required.

So, as we have seen volume of production is directly related to the cost, the cost that we incurred in setting up of the equipment. So, setting up of the equipment also includes the furnace where we are going to heat the metal. So, if heating is required, there is additional investment in the form of a furnace, whereas in cold working we do not require to heat the metal. So when, heating is not required the furnace is not required, so the cost incurred add the initial setup will be comparatively less.

So, no heating is required in case of cold working, better surface finish is obtained, so if better surface finish is obtained. We may not be requiring any of the subsequent finishing operations, finishing operations will add to the cost of the final product. So, if we are getting the product in the near net shape, and no further or subsequent finishing or machining is required, then the cost will be comparatively less. So, if the surface finish is good, we need not go for machining and finishing operation. Then better dimensional control is achieve, no secondary machining is generally needed.

So, already in the second point I have explained, that if the surface finish that we achieve is considerably good. Then subsequent machining and grinding, and lapping and horning are any of the finishing operation is not required. So, in cold working the three basic advantages, over hot working or that no heating is required in case of cold working, better surface finish is obtained in case of cold working. And better dimensional control is possible in case of cold working, which is not possible using the hot working operation.

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Then products possess better reproducibility and inter changeability, so inter changeability is a important concept wherever we are going for mass production processes. So, whenever we go for mass production, we need to have the concept of inter changeability, So, the products that are made using cold working they are better reproducible, moreover they have the property of inter changeability, why this property of inter changeability is coming into picture?

Because of the better dimensional control as well as a very good surface finish, which is possible using the process of cold working? Then the products that we are making using of the cold working process, they are they have better strength, better fatigue properties, and the wear resistance is also very, very good. So, wear properties of material is good, the strength is also good, and moreover the fatigue characteristics are also good. So, fatigue characteristics basically come into picture, if we have some surface cracks.

So, if there are certain small cracks of micro size present on the surface of the final product, whenever it is applied, whenever it is used under cyclic loading or it is used under any kind of load, where the load is varying with time. So, the chance is of the propagation of that crack is possible. So that, crack when it will propagate after some cycles of loading, after sometime there are chances of the failure of the product. So, the fatigue characteristic of the material that we are forming, that we are producing with that hot or the cold working operations should be very, very good.

So, here in this point we have seen that better strength fatigue and wear properties of the material. So, the fatigue characteristics or the fatigue properties of the product that we are making use of by the cold working operation are very, very good. Then, the directional properties can be imparted, so directional properties basically mean the property of un isotropy. So, either the material will be isotropic or the material will be un isotropic.

So, if you want to have certain properties in one particular direction, those properties can easily be imparted using the cold working operations like. We can see that the crane hook, the hook of a crane which is used lift the load can be designed in such a way that it has certain directional properties, along the cross section of the hook. So now, depending upon what type of properties are required in the hook, we can design the hook and those kind of properties or the directional properties can be imparted using the process of cold working.

Then contamination problems are almost negligible, why contamination problems are negligible? Because, sometimes we see some kind of scale is farm on the surface of the metal, so why that scaling takes place. Because, at elevated temperature the product may react with the atmospheric oxygen or it may react with the environment to form certain type of scale, but here as the temperature is not an elevated temperature, the temperature is not above the recrystallization temperature. So, that property or that surface finish or the scaling is avoided, and the surface finish that we get is up to the desired levels.

Moreover, the contamination or the deterioration of the surface or the oxidation of the surface, which is possible at higher temperatures is avoided using the process of cold working. So, we have seen that there are certain advantages of cold working operations over the hot working operation, but it is only one side of coin there are certain limitations also, which are possible using the cold working operations.

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So, what are these limitations? Higher forces are required for deformations, so whenever the metal is at a elevated temperature, ductility increases it is strength decreases. So, reduced strength increase ductility will help to form the metal in the desired shape, but in case of cold working we need there is no elevated temperature. So, at room temperatures, when we are working higher forces are required for deformation. So, the equipment or whatever machine we are using for the cold working operation should be very steady.

It should have resistance to different types of vibrations that are generated, and it should not break under the applied loads, sometimes there are may be some cracks in the bed of the metal or the bed of the machine. So that, may at some later stage under some loading, because this is not a single operation, it is a cyclic type of loading that is coming. Always, we are pressing or we are using the hammer or the punch to change the shape, so under this kind of cyclic loading sometime if the bed is not steady it may break.

So, higher forces are there, so the machine should also fit into the domain of this avoiding the vibrations, and avoiding the fatigue type of fractures. So whenever, we are going to make use of a cold working operation, higher forces are going to be encountered, and the machine that we are going to use for cold working should be able to sustain those kinds of forces. Then heavier and more powerful equipment is required, already in the first point, it has been explained that heavier and more powerful equipment is required in case of cold working operations.

Then, whenever we are making use of cold working, the less ductility is available. So, ductility or the deformation property is less. So, in order to increase the ductility, what we can do? We can slightly raise the temperature in order to improve the ductility of the metal. So, cold working has a number of advantages over hot working, but there are certain limitations areas, which have been addressed in this slide.

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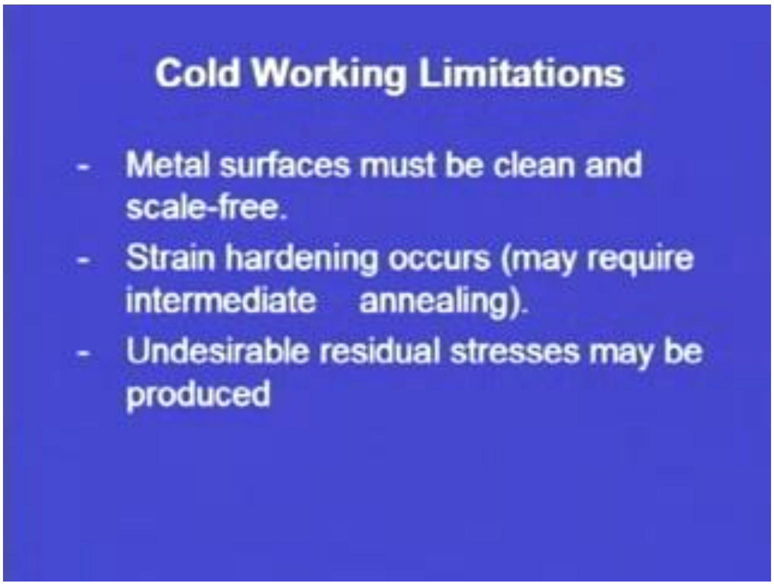

Now, there are other cold working limitations like metal surfaces must be clean and scale free. Already we have discussed that the metal or the surface of the metal that we are getting, after the cold working operations is free from any kind of contamination. But, before working we have to make it sure that it is clean, and there is no scale present on the surface of the metal. Moreover, in cold working operations sometimes strain hardening occurs, and this may require intermediate annealing. So, now intermediate annealing I am not going to explain in detail, that what is the process of annealing?

It is basically raising the temperature, and then cooling the material or the cooling the product in order to remove the effect of strain hardening. So, strain hardening is the property that may develop, when we are cold working the metal. Then, undesirable residual stresses may be produced, now these residual stresses that are produced during the process of cold working, may later on affect the in service performance of the product. So, these residual stresses sometimes may result in a failure of a material or the product that has been made using the cold working operations.

Now, we come on to the warm working operations, so we have seen a cold working operation, what is cold working? How it is compared with hot working operations. Now the comparison basically was in terms of advantages, and it was in terms of limitations. So, cold working has certain advantages over the hot working, moreover it has certain limitations which have to be removed, if cold working has to be carried on a particular raw material to convert it into the final shape. In between, the cold working as well as the hot working, there is another sub category of metal forming operations that is warm working.

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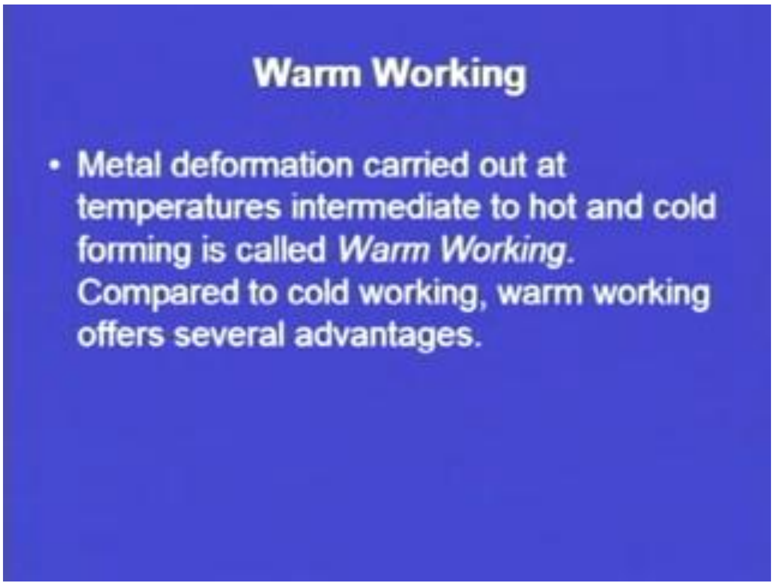

So, basically what is warm working? Metal deformation carried out at a temperature, intermediate to hot and cold forming or the cold working is called warm working. So, intermediate temperature it is not very high, it is not very less or it is above the room temperature, but below the recrystallization temperature. So, the metal deformation that is carried out in the intermediate range between cold and hot working is the warm working.

Now, compared to cold working, warm working offer several advantages, as we have seen, the advantages and limitation of cold working in comparison to hot working. Now, we will see the advantages and limitations of warm working as compared to cold working, as well as compared to hot working.

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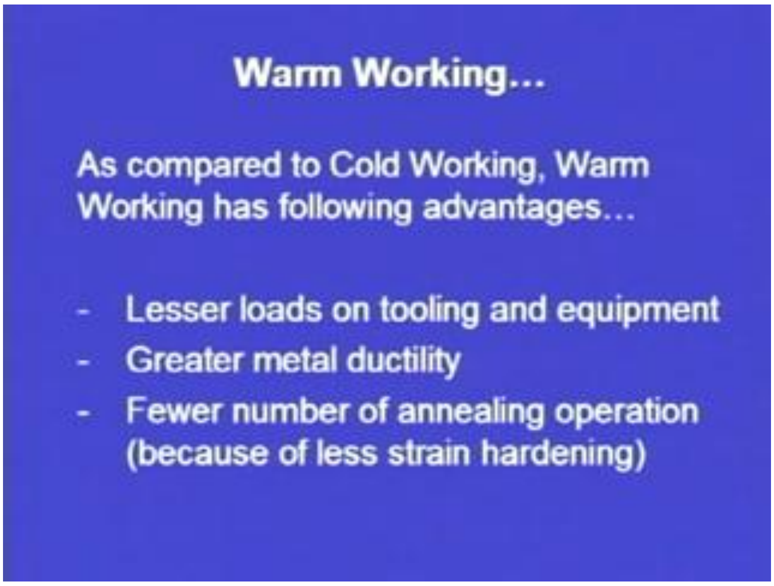

Now, warm working basically as compared to cold working has following advantages. Lesser loads on tooling and equipment, already limitations of cold working we have seen, the machine should be heavy they should be able to sustain the loading. So, in case of warm working, lesser load on tool and equipment is present. Moreover greater metal ductility, the ductility is improving in case of warm working which was considerably less in case of cold working. Fewer numbers of annealing operations are required, as when hardening takes place. So, immediate annealing is required after cold working, but here fewer numbers of annealing operations are required, because of less strain hardening.

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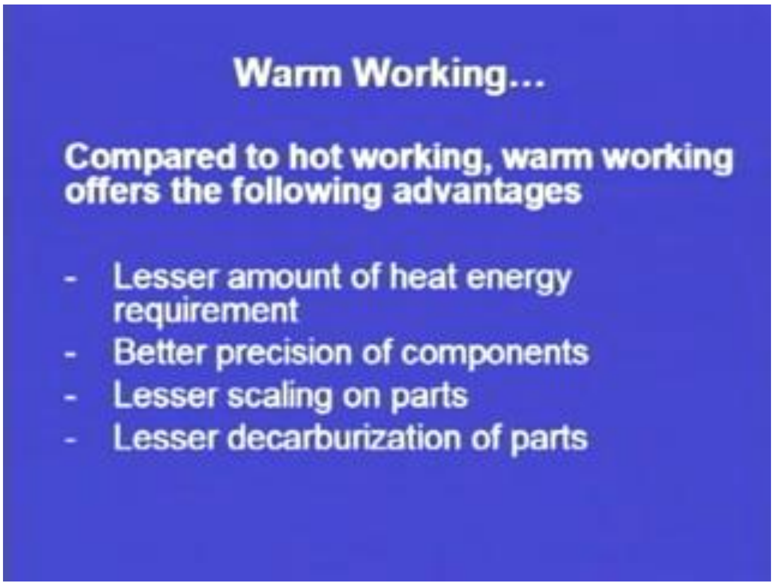

Now, warm working compared to hot working also, warm working offer certain advantages, now what are these advantages of warm working. As compared to hot working, these are lesser amount of heat energy is required, because we were slightly elevating the temperature, we are not going beyond the recrystallization temperature. Better precision of components is there, so the precision or the accuracy of a surface finish or the dimensional control is better. Lesser scaling on parts, so no scale formation on the surface of the parts takes place. Lesser decarburization of parts, so decarburization is also less whenever we warm work a metal as compared to the hot working.

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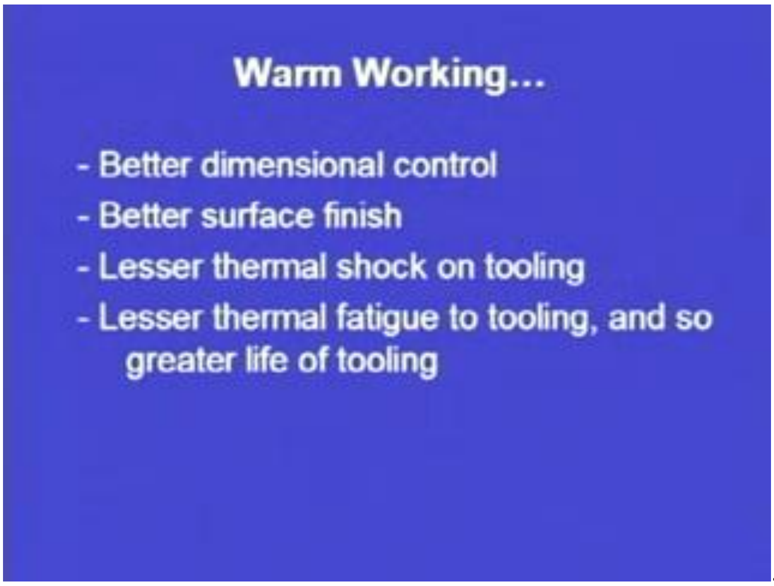

Now, with warm working already I have mentioned, the better dimensional control is there. Better surface finish is obtained using the warm working operation. Lesser thermal shock on tooling, now thermal shock basically, whenever the tooling is coming in contact with the elevated or the work piece at an elevated temperature. So, some kind of thermal shock may take place. So, here as the temperatures are less, the thermal shock on tooling is also comparatively less, lesser thermal fatigue to tooling and so greater life of tooling. So, the fatigue life or the life of the tooling is more as compared to the hot working tools, so whatever tooling we are using for hot working, the life is considerably less as compared to the life of the tools or the life of the dyes, that we are making use of in warm working operations.

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So, we have seen till now under hot cold and warm working, what is cold working? What is warm working? How hot and how cold and warm working are related to hot working in terms of their advantages, as well as in terms of their limitations. Now, coming on to the third and the last subcategory of metal forming operations, like I have already told metal forming or metal deformation processes, can broadly be categorized into three different subcategories, that one cold working, warm working and hot working.

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So, hot working what is basically hot working? Plastic deformation of metal carried out at a temperature above the recrystallization temperature. So, important point to mention here is that we are working on the metal at an elevated temperature; the limit of that temperature is above the recrystallization temperature. And whenever we are working above the recrystallization temperature, we will call that metal forming operation as a hot working operation.

Now, under the action of heat and force, as the temperature is a elevated temperature it is above the recrystallization temperature. So, under the action of heat and force, whenever the atoms of a metal reach a certain higher energy level, so atoms will reach a higher energy level, the new crystals start forming this is called recrystallization. So, we have seen that recrystallization temperature is a limiting factor to distinguish between hot working and cold working, what is recrystallization? Just I will summarize one again.

Under the action of heat and force, whenever the atoms of the metal reach a certain higher energy level, the new crystals start to form and this is called recrystallization. And the temperature at which this happens is called the recrystallization temperature. So, whenever we are working above this temperature it will be categorized as hot working, whenever we are working below this temperature it will be characterized as cold working.

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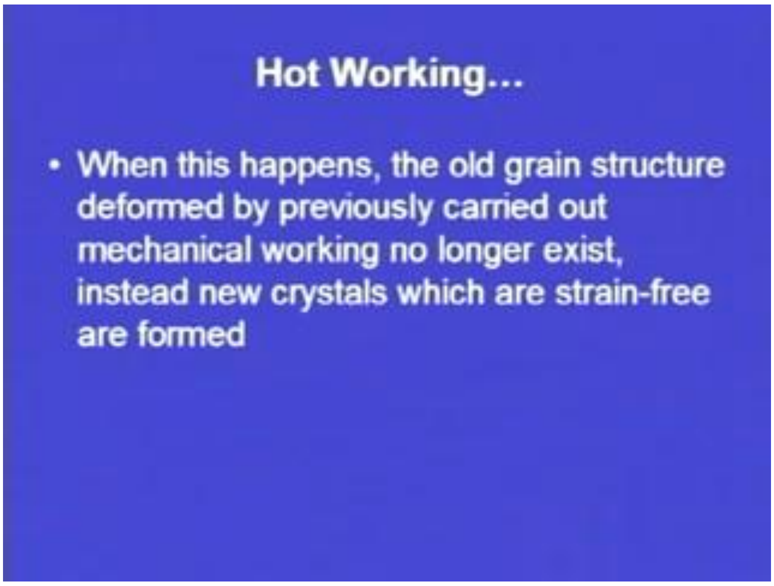

So, when this happens the old grain structure deforms by previously carried out mechanical working no longer exist. So whenever, this recrystallization takes place, old grain structure that has been deformed or that has been formed, by previous working or the previous cold working or hot working that will no longer exist. And instead new crystals, which are strain free are formed. So, strain free crystals will be formed, after the process of hot working. So whenever, we are raising the temperature above the recrystallization temperature, the old grain structure that has been deformed earlier will be removed or it will no longer exist. And new crystals will be formed, and these crystals basically will be stain free crystals.

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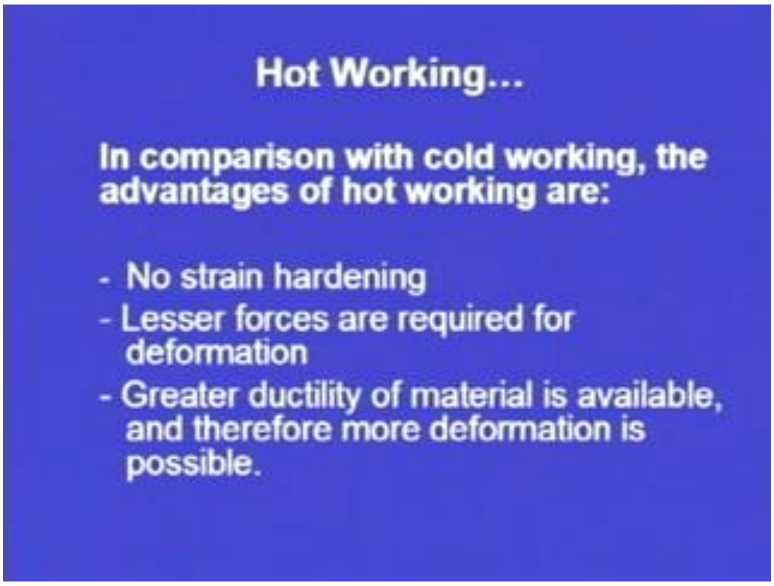

Now, hot working in comparison with hot cold working the advantages of hot working are that there is no strain hardening. So, we have seen that stain hardening takes place in case of cold working. And strain hardening will limit the further deformation, and when the material has strain hardened, the deformation or whatever changes that we want to make will be limited. Lesser forces are required for deformation, as at an elevated temperature we have seen where the ductility is improved the strength is reduced. So, lesser forces are required for deformation.

Moreover greater ductility of material is available; already we have seen at elevated temperature above the recrystallization temperature, the ductility that is available with us is considerably more. So, if the ductility is more, the deformation that is possible in the metal is considerably higher. So, greater ductility of the material is available and therefore, more deformation is possible. Now, we have seen that cold working and hot working are two important processes for converting a raw material into a final product. So, we have here, we have seen that how hot working compares to cold working in terms of its advantages.

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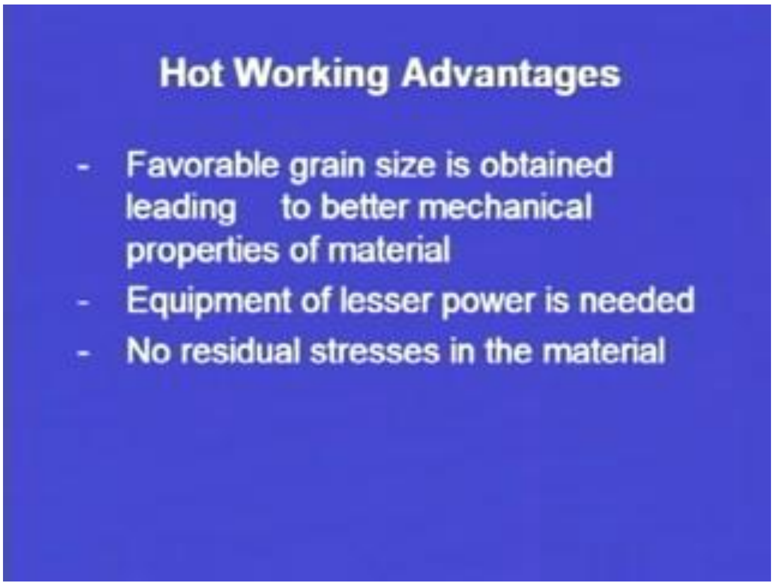

Now, we have seen there are three distinct advantages of hot working over cold working. So, there are other advantages possible with hot working, so the hot working advantages are favorable grain size is obtained leading to better mechanical properties of material. As most strain hardening takes place, and grain size that we get in hot working is very good or is favorable.

We cannot say a grain size is good or bad, but it is favorable as in relation to the mechanical properties that are desirable. So, whatever product we are making, we have a favorable grain size and depending upon the grain size, there will be certain mechanical properties of the final product. So, the grain size that we get in case of hot working is favorable, and we get the desired mechanical properties of the final product.

Similarly, equipment of lesser power is needed, so as we have high ductility reduced strength of the material, the equipment that is required should not be that steady, it should not have that kind of re characteristics or the bed should not be the steady. So, equipment of lesser power is needed, lesser power is required for changing the shape of the metal from a raw material or from a rod, plate, sheet into it is final form.

No residual stresses in the material are present. So, the no residual stresses are present. So, some type of failures that may take place, because of this residual stresses in the, in service performance of the metal or the product that has been formed using hot working, that kind of problem is avoided. No residual stresses are present, means that metal or the product is going to behave in it is desired manner, and no failure or no fracture, etcetera, is take going to take place, because of this residual stresses present in the metal.

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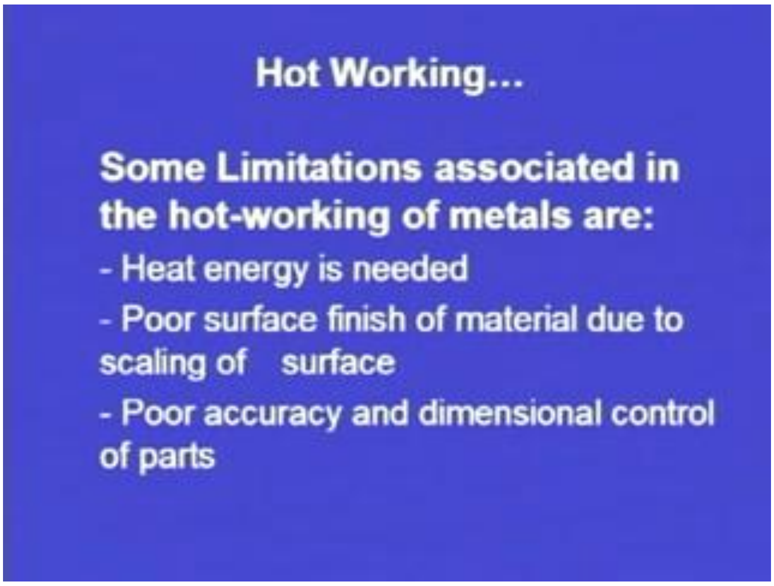

Then hot working also has certain limitations. So, some of the limitations that are associated with hot working of metals are advantages already we have seen. Hot working has certain advantages in comparison to cold working, but it also has certain limitations, what are these limitations? The heat energy is needed, so we need a furnace to heat a metal, before we can hot work it. Poor surface finish of material due to scaling of surface, so the surface finish that we get using the hot working operation is not up to the desired level.

So, we need to go for subsequent machining, and finishing operations in order to remove this scale, so it adds another operation. So, we can see two additional operations have been added, the first one is the heating of the metal, and the second one is the finishing or the machining of the final product, after the hot working of metals. Poor accuracy and dimensional control of parts, so the accuracy that we get of the final product, is not up to the desired level or is not up to the specifications. And the dimensional control of parts is also poor. So, accuracy is not good, and the dimensional control is not up to the desired level.

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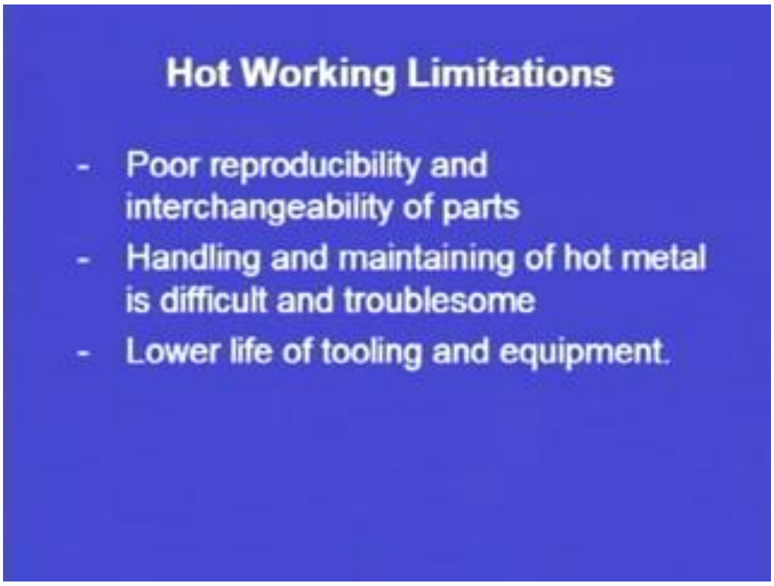

Now, other limitations of hot working are poor reproducibility and interchangeability of parts. Handling and maintaining of hot metal is difficult and troublesome. And lower life of tooling and equipment, this may be because of the thermal shock or some other reasons, but the life of the tooling is comparatively less in case of hot working operations.

So now, we come towards the end of first lecture on metal forming. In this lecture, we have seen that what are the basic manufacturing processes? Where do metal forming fit into the manufacturing spectrum? What are the different types of metal forming operations? What are the states of stresses prevalent, while undergoing these type of metal forming operations?

Then we came on to discuss, what is cold working? What is hot working? What is warm working? And in discussing hot working, cold working and warm working the relative advantages and limitations of all these working operations were discussed, and some of the points were highlighted in detail. So, we will start our next session on forging operation. So, we will discuss the details regarding the forging operation in the next lecture.

Thank you.