Fundamentals of Manufacturing Processes
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Lecture - 08
Effect of Manufacturing Processes on Mechanical Properties

Hello, I welcome you all in this presentation. This presentation is related with the subject fundamentals of the manufacturing processes and today we will be talking about the effect of manufacturing processes on the mechanical properties of the component being produced. We know that whenever any component is designed it considers the mechanical properties of the material while fixing the design, while fixing the size and shape.

Those are design properties or the properties which are used for the design purpose are considered in properties for the design purposes are considered to fix up the size and shape to be used, so that the component can perform the function desired.

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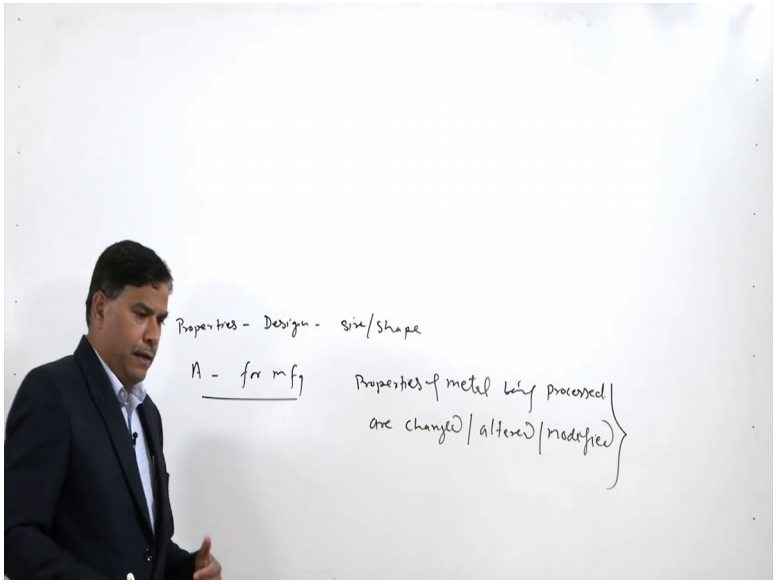

But we know that say if A metal is offering these properties and it is selected for manufacturing, but when we manufacture the when we process the material a using manufacturing processes the properties are affected and we do not get the same range of the properties by all manufacturing processes.

We need to consider means the point is the properties of the material properties of the metal being processed are changed altered or modified, the what kind of modification or change in properties of the material takes place that we need to see. So, that even after the manufacturing the final product whatever is made has the required set of the property.

We need to keep in mind the way by which the properties of the material especially the mechanical properties of the material will be affected or altered by the manufacturing processes. So, to look into this aspect will be going through the fundamental mechanisms that affect the mechanical properties of the material, for this we need to see like the metal strengthening mechanisms, metal strengthening mechanisms.

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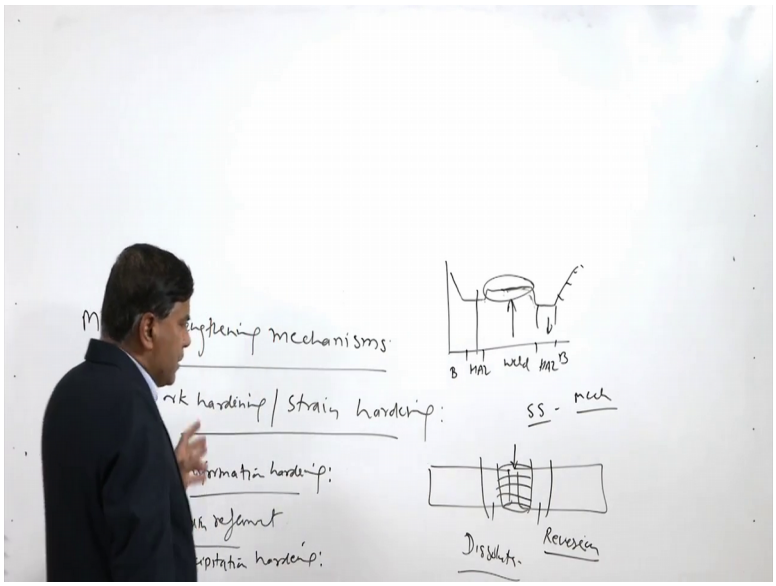

There are 4, 5 mechanisms which significantly affect the mechanical properties of the metals during the manufacturing and those we will try to talk about just a brief overview of these mechanisms I will be giving.

One is the work hardening this is also known as strain hardening, a strain hardening occurs whenever there is plastic deformation of the material however the extent of a change in increase in a strength and hardness due to the a strain hardening or work hardening due to the plastic deformation can vary with the work hardening behaviour of the material. So, they are few metals which work hard and very rapidly and they result in significant increase in a strengthen hardness as compared to others.

For example, austenitic stainless steel and the aluminum, aluminum work hard is more rapidly than the aluminum and their extent of work hardening is very limited for the aluminum and this is attributed to the development the change in properties is attributed to the development of the large number of the dislocations in the metal during the due to the deformation.

So, more number of the dislocations they interfere the dislocations movement and which in turn increases the resistance to the deformation, resistance to the yielding and that is how the increase in a strength and the hardness takes place. However, this also leads to the reduction in ductility and the toughness of the metal due to the work hardening.

We need to quantify really there is not much compromise with regard to the ductility and the toughness while the increase in a strength is taking place. Another the mechanism that affect the metal properties during the manufacturing is like transformation hardening this work hardening or a strain hardening is a primarily related with those processes where deformation takes place, so inor surface layer deformation in machining or large scale deformation in case of the forming based processes, these are the 2 category of the process where the some kind of the work hardening and the deformation will be occurring during the manufacturing.

In the transformation hardening processes like if the excessive heat is generated during the machining then also it can lead to. So, like rough or improper grinding generating excessive heat leading to the transformation hardening forming the hardest parts or casting and welding.

And machining processes where the heat is used for melting and abolition of the metal there also transformation hardening can occur, machining using the heat for melting or the abolition. So, in all these cases whenever the manufacturing conditions like grinding, casting, welding or machining are such that after heating to the high temperature where austenitization of the steel takes place followed by the rapid cooling in that case the transformation hardening occurs.

The hardening may be in form of like say normalizing or quenching, this basically occurs in case of the hardeable or heat treatable steels heat treatable steels. Whenever these are heated to the austenitic state during the manufacturing austenitic state and followed by the cooling. If the cooling is faster than it will be leading to the normalizing, but if it is

very fast like quenching in water or oil then it will be leading to the hardening or martensitic transformation from the austenitic state.

So, that in turn will be increasing the strength and hardness, in case of the normalizing basically refinement of the grain structure or like pearlite, ferrite etcetera needs to the increase in a strength and the hardness strength and hardness of the a steel, but without much compromise with toughness and ductility both.

In that way this is a good a process on the other hand the transformation hardening causes the significant increase in a strength and hardness due to the martensitic transformation. So, it in that case like quenching or hardening involving the martensitic transformation, in that case we get the significant increase in the hardness say from 20 HRC to 50 to 55 HRC that is the Rockwell hardness on C scale and at the same time a strength also increases, but at the cost of the ductility as well as in the toughness, both these reduce.

We need to consider that whenever due to the a manufacturing conditions during the grinding or the casting or the welding if the cooling conditions are such that martensitic transformation takes place then it will be leading to the increase in hardness strength, but at the cost of the ductility and toughness, this is what should be kept in mind and if it is. So, we need proper post manufacturing treatment in order to induce the ductility and the toughness through the tempering process.

Then the third mechanism is the Grain refinement we know that the in general the fine grain is structure results in the increased strength, hardness, ductility and toughness, all these are favorable, toughness is strength ductility everything is improved. This is the only method which increases the strength and hardness without compromising the toughness and ductility.

This is very good method in that way and depending upon the cooling conditions during the welding and casting, the casting, welding and those machining process where melting and fusion is involved like as cast or recast layer is produced in processes like laser machining or the electro discharge machining. In all those processes wherever solidification is involved the refinement of the grain effects the mechanical properties and you know that depending upon the cooling rate experienced by the metal cooling

rate experienced by metal during solidification or in the solid state cooling from high temperature to the room temperature the grain structure this affects the grain structure.

In general you know the finer the grain structure better the mechanical properties in terms of a strength hardness, toughness and ductility and it is the cooling rate that which is experienced by the metal being processed either during the welding casting or machining, thermal based processes of machining, the solidification, during the solidification whatever is the cooling rate experienced by the metal that determines the grain size.

In general high cooling rate results in the finer grain structure, this is what we can see. If the like the weld pull size is very small then it will be quenched rapidly as compared to the case when the weld pull size is very big. In that case lot of heat will be a need to be extracted from the weld metal and it will be transferred to the base metal.

In this case cooling rate will be low and in this case cooling rate will be high and, low cooling rate will be resulting the coarse are grain structure and engine poorer mechanical robot is in terms of the strength, toughness, ductility. If no other transformation is taking place and similarly similar can be the case for the sand mould castings like the sand being of the low thermal conductivity or it transfers the heat from the molten metal slowly, this is the mould and this is the molten metal.

The molten metal in case of sand mould casting since experience is the low cooling rate, say because sand is of the lower thermal conductivity. It extracts the heat from the molten metal slowly, low cooling rate in case of the sand mould casting results in the large grain size or coarse grain structure or large grain sizes which in turn results in the somewhat poorer mechanical properties as compared to the case when the metal mould is used. Metal mould since the metals are of the metal thermal connectivity they extract the heat from the molten metal very quickly and, the cooling rate is a high which in turn results in the finer grain a structure and, the better mechanical properties are experienced are produced in the metal mould casting, in case of metal mould casting as compared to the sand mould castings.

There is one more mechanism that can be important in determining the mechanical properties of the material during the manufacturing that is the precipitation hardening. This mechanism works in those cases or it is important in those cases where the

precipitation strengthening is the mechanism that is governing the strength of the given metal.

In this case what happens the metal matrix metal pure metals they are soft and ductile, these need to be a strengthened and this is strengthening is achieved through the development of precipitates. Precipitates like say in most of the non ferrous metals these precipitates in control way or developed so, that they can offer the improved mechanical properties.

These precipitates are actually of very fine in size maybe of like say 10 to 10000 angstrom and, but this is say maybe thickness and similarly the diameter. So, thickness as well as the diameter it is very fine and very thin, under the effect of heat these tend to get dissolve. These fine precipitates present in the metal matrix which is soft and ductile, when these precipitates are present the strength is good, but due do the effect of heat when these get dissolved in the metal matrix the strength is reduced.

This dissolution is called reversion, for example, in case of the aluminum copper alloys CuAl2 is the typical precipitate which is which is strengthens the aluminum matrix. Similarly in case of the aluminum magnesium silicon systems Mg2Si is the another precipitate and these precipitates being are of verifying size under the effect of the heat above certain temperature this get dissolved normally the heating in range of 150 to the 250 degree centigrade most of these precipitates tend to get dissolve and once they get dissolve the strength loss takes place. Those processes wherever heat is used and the base metal is subjected not just for melting, but if the heating is leading to the dissolution of this precipitates then that will be affecting the mechanical properties of the material.

There are 2 aspects one whether like say this is the piece and if it is one portion is brought to the molten state, all the precipitates which will be there will get dissolve and here will get that everything is in solid solution a state whatever precipitates where there they will be there in the solid solution state. Whether there precipitation is possible or not during the cooling conditions that is one thing and that will be affecting to the mechanical properties and if these re precipitates under the given cooling conditions then of course, is strength will be restored otherwise there will be loss of the a strength.

On the other hand what about those systems or those locations which have been heated next to the fusion zone. So, in these this is the area where partial or complete reversion of

the reversion or dissolution of the precipitates will be taking place in all those locations where such kind of reversion take place then will be finding the significant loss of the a strength. So, here if will try to plot the hardness of the like this is this side base this side base this is the heat affected zone and this is the weld and this is the (Refer Time 21:04) zone.

So, depending upon the precipitation in the weld region find the behaviour of this kind, the base metal is having higher hardness, as a z is this having the lower hardness and if the partial precipitation takes place then the weld will also be having the good hardness. There is a region which will have the lower hardness due to this reversion or the dissolution; especially in aluminum magnesium systems this kind of behaviour takes place.

I mean to say wherever there is a rise in temperature during the manufacturing of this precipitation strengthened systems there will be change in mechanical properties depending upon the extent is precipitates get dissolve under the influence of heat. Now coming to the specific casting processes and factors that will be governing the mechanical properties.

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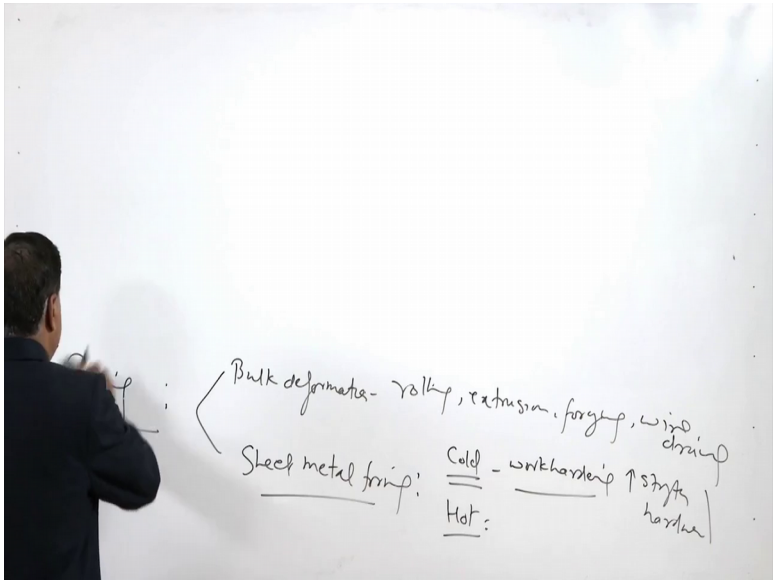

Here you know casting the in case of the casting properties are affected by the 2 aspects, one is the soundness whether it there are porosity inclusions are not, on another is the structural micro structural part. The 4 types of the structures are found in case of the

castings like these are the planner, cellular, dendritic and equest, this results in the very soft and very low hardness are it is mostly found in case of the pure metal systems and then increasing a strength and the hardness of the material.

Here somewhat better a strength and hardness in case of the cellular and it is strong, but of the low ductility and here the equest one offers the very good combination of the mechanical property. Equest structure is the most desirable structure in case of the casting another is, this is about the shape and another aspect related is the structure is the fines.

Those processes those casting processes where fine grain structure is produced like in the die casting or metal mould casting cooling rate is high. So, that results in the fine grain structure which in turn produces the very good combination of the mechanical properties as compared to the sand mould casting, which due to the lower cooling rates results in the coarser grain structure and therefore, the castings made by the sand mould casting or somewhat poorer as compared to the a metal mould casting or the die casting process.

Another is a forming base processes used they are 2 category of the forming base process one is where the bulk deformation is involved like in processes rolling, extrusion, forging wire drawing etcetera. In all these cases large scale deformation is involved and in case of the sheet metal forming simpler or somewhat less extent of the deformation takes sheet metal forming like bending, a stretching and in the process like quenching some deformation is involved.

In these processes where deformation is involved if you take us at low temperature like in cold process where those are carried out at the room temperature the deformation leads to the significant work hardening and this work hardening actually increases the strength and the hardness; however, at the cost of the ductility and toughness, but sometimes there is no major drop or compromise with a strengthened the toughness.

On the other hand the hot processor like hottest forging or hot extrusion in that case work hardening extent of work hardening is limited, but the microstructure is well control for the grain refinement. So, that desired combination of the mechanical properties can be achieved under that is why for realizing the very high strength to weight ratio aspect in the products which are made by the forming based processes most of the automotive

components are subjected to the bulk deformation based processes, that they strength and a strength to weight ratio of the product can be improved.

Then we have the machining, in case of machining actually very near surface layers machining mechanical based machining processes.

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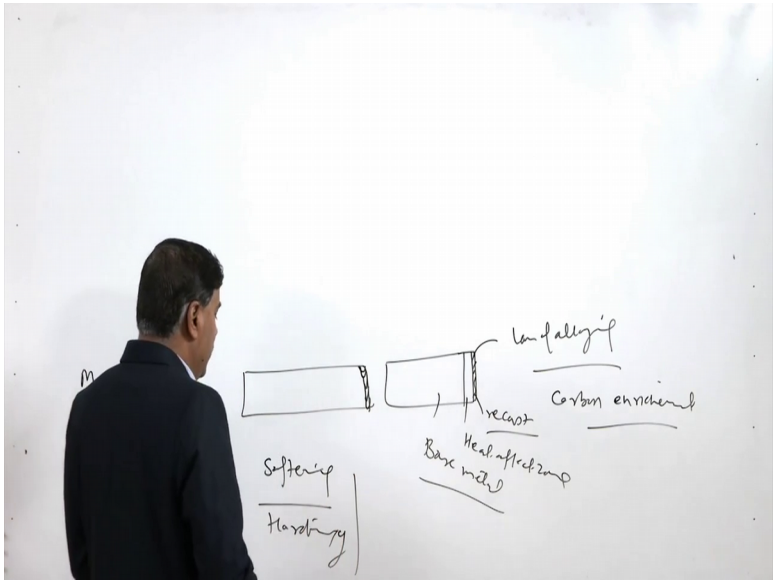

Where shear forces used for or shearing is involved shear mechanism is involved for removal of the material a very thin layer of say 50 to 100 micrometer is a left at the surface after removal of the material in form of the chips and this layer is primarily elastically deformed this is under the elastic deformation state and this elastic deformation states leads the leads to the I can say compressive residual stresses and these compressive are considered to be the favorable for the metal system.

But if the very abusive machining is carried out then we may have that below this elastically deformed layer we may have a region which is under the plastic deformation and this plastic deformation plastically deformed layer may will have the effect of the work hardening, but those machining processes were thermal energy is used for either melting or for the evaporation or abelson like in laser plasma or gas cutting.

In those cases definitely wherever these this energy is applied the melting of the material sequentially helps to make a cut through the thickness and a remove the material to achieve the desired size and shape, but in this case we find basically 3 zones one is the

layer which will be resolidifying. This is called recast layer it will have that cast structure there after it there will be one heat affected zone and then the base metal.

These are the 3 regions which will be there sometimes as per the method being used there can be the loss of alloying elements from this layer and there maybe even the carbon enrichment if the carburizing flame is used, in there can be carbon enrichment in this region. So, as per the as per the strengthening mechanism being used in the given metal the metal may result in the mille to the softening due to the reversion or it may be subjected to the hardening due to the transformation hardening.

These are the 2 heat based heat related effects softening or hardening, softening due to the reversion or coarsening of the grain structure or hardening due to the transformation hardening related with the material for the heat treatable systems coming to the welding as I have said.

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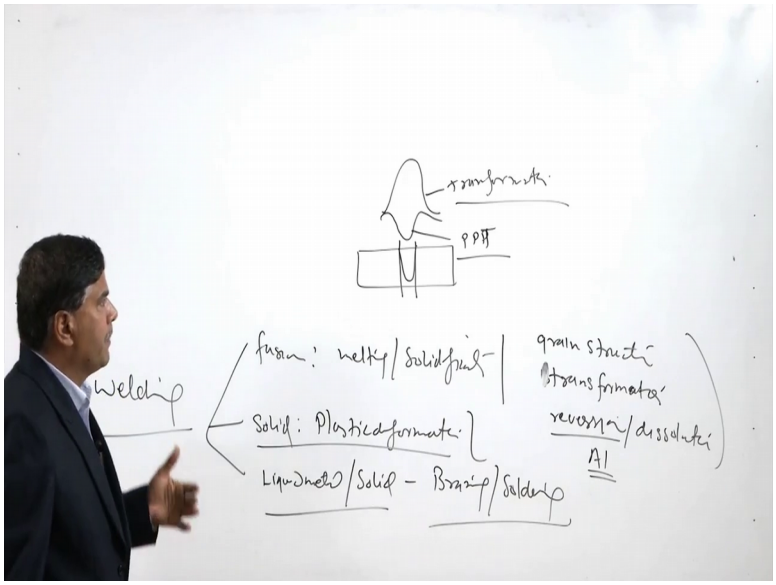

They are 3 types of the processes like fusion welding, then solid state welding, and then those processes where the liquid metal of the low melting point is used and the base metal remains in the solid state, these are called liquid solid based processes and these are like brazing and shouldering.

In the solid is in this case basically the plastic deformation is the mechanism in the solid state welding processes and the fusion of course, the melting followed by solidification is

involved in this processes. So, as I have said depending upon the in the cooling rate experienced by the fusion welding processes and the transformation hardening these are the 2 things the grain structure as per the cooling rate and the transformation hardening in case of the heat treatable steel transformation hardening in case of the heat treatable a steels and a like a reversion or loss of the alloying reversion or dissolution of the precipitates is are the precipitation hardenable systems these are the things which are involved.

Similarly, in case of the plastic deformation also these things are involved because a lot of heat is generated which will leading to the austenitization in case of the steels that also leads to the due to extensive deformation it leads to the finer grain structure as well as the reversion in dissolution in case of the aluminum alloys and the precipitation hardenable alloy. So, depending upon the kind of the metal systems the plastically deformed the solid state joining process may lead to the development of the weld where in the nugget area may offer you much higher hardness or it may lower the hardness. So, this true for the precipitation hardenable systems and this is for transformation hardenable system. If the transformation of the steel takes place transformation in case of the steel welding takes place into the martensite than the hardening will be occurring and if there is loss of precipitates than softening will be occurring in case of the precipitation hardenable alloys.

Thank you for your attention.