Automation in Manufacturing
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Week- 03
Selection and fabrication
Lecture – 04
Fabrication Process

Hello, everyone. I welcome you all to the 4th lecture of week 3. In week 3 we are looking at various Selection and Fabrication criteria and methods, which are required to build an automated system. Well in this lecture, we will be learning at primary level the various Fabrication Processes.

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The outline of this course is as follows. At the start of the lecture, we will have an overview of various fabrication processes which are used. Then, the basic manufacturing processes such as casting, forming, joining and machining will be discussed. In addition to that, the next generation manufacturing process, i.e the additive manufacturing process, will be seen at an introductory level.

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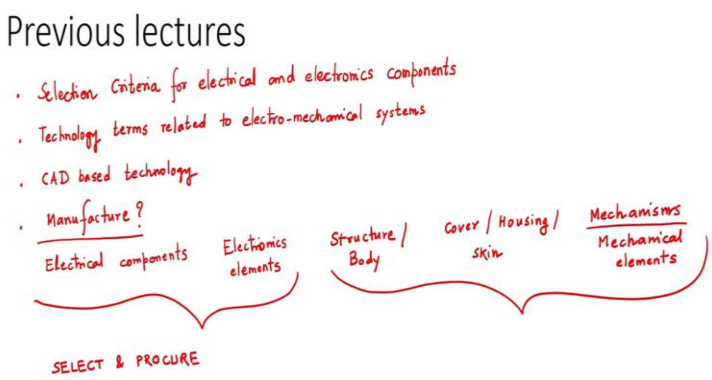

Let us have a quick review of the content that we have seen in the week 3 lectures. If we remember, we have seen the selection criteria for electrical and electronics components that are required to build an automated system. After that we studied various technology terms, related to electromechanical systems and sensors in particular. Then we have seen various CAD based technologies required for design and fabrication of the automated system.

Now, comes how to manufacture various elements of an automated system. In this lecture, we will discuss what are the various components which are there in a typical automated system.

A typical automated system may have electrical components, electronics elements, the structure or the body of the system. The structure or the body will have the scheme or the housing or the cover; and the automated system will have a variety of mechanisms which are the mechanical elements. The structure, cover, housing and skin are also the mechanical elements.

The electrical components and electronics elements are selected based on the requirement and then procure them. For the standard parts which are available such as the electrical drives, various sensors, actuators, signal conditioning devices, microprocessors, all memory elements, the designer has to choose and the company has to purchase from the market. In previous class we have seen the criteria in detail. In today's class we will be studying. How to manufacture the mechanical elements? In this mechanical elements, some of the elements are again possible to have in a readymade format, no need to manufacture them in house. But, some of the elements are to be designed and manufactured in-house. These are the customized elements, these are the customized parts, required to build our manufacturing system our automated manufacturing system.

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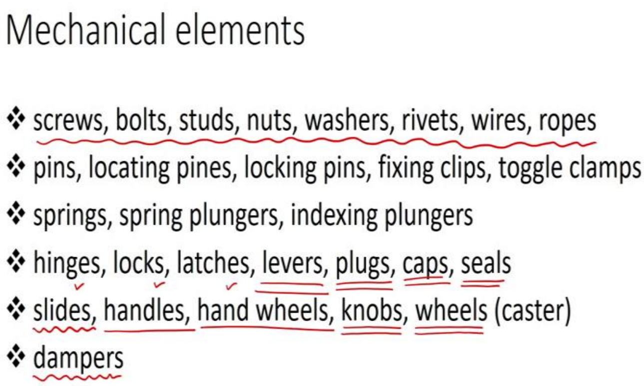

Now, let us see what are the various elements that you can easily procure from the market. If we look at the construction of an automated system or any machinery or a machine tool, we will find that there are various components, such as screws, bolts, studs, nuts, washers, rivets wires and ropes. All these elements are used as temporary fastening elements.

If we want to assemble the sub assemblies or various parts of our system, we need to fasten them together. We can have either a temporary fastening or the permanent fastening. To have the temporary fastening or semi permanent joining, we are using the screws, bolts, nuts, washers, rivets, wires and ropes.

In addition to this we require pins, clips and toggle clamps. Pins are required again for the fastening or the location purpose, for fixing purpose and the clamps are required to hold the parts, to fix the parts. We may also require various springs; springs plungers or indexing plungers.

The system also requires hinges, locks, latches, various levers to operate the machine tool or to operate the automated system. For the operation of the hydraulic system, we need to have the plugs. The system also required to have caps and seals to avoid the leakage of the liquid. There are various slides, handles hand wheels incorporated for handling of various parts of the system.

Various knobs are also there and wheels for maneuvering of the system for the conveyance of the system from one location to other location. The automated systems are working on application of variety of forces. In the application of the forces there may be chances to have the vibrations in the system.

It is also required to have various dampers. All these components are readily available in the market, only we have to choose a proper element, we have to finalize the specifications as per our need and then we have to go for purchase of this components.

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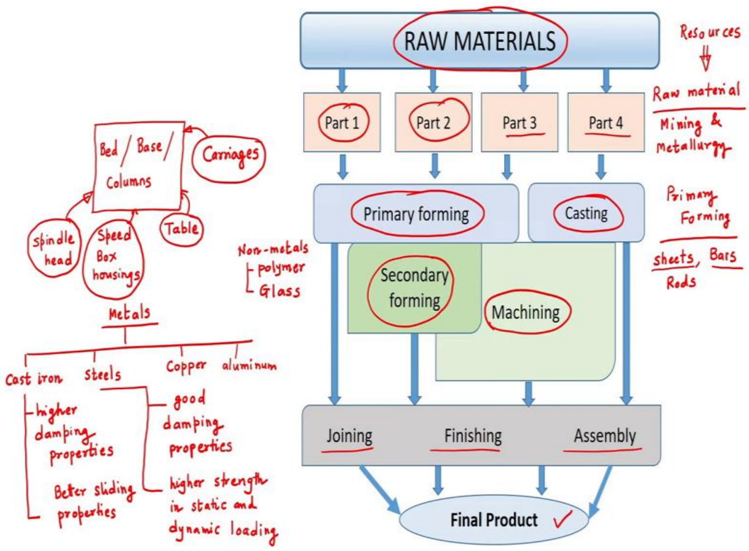

However, as I mentioned in my previous slide what are the various things that need to be designed and manufacture in house? In particular, if we look at the construction of a typical automated system, we may require to have a bed or a base or columns. Bed, base and columns are made up of metals. On these basic structural elements, we are putting up various sub-assemblies and these sub-assemblies may be spindle head, speed box housings, various tables, various carriages, so on and so forth. All these sub-assemblies will be integrated on the bed or base or the columns of a typical automated system.

Well these mechanical elements, as I mentioned are particularly manufactured by using metals. In metals, mainly the cast iron and steel are used to fabricate these elements. Cast iron provides higher damping characteristics, the cast iron has very good toughness. So, in case of in case of application of the dynamic loading or intermittent loading, the cast iron will absorb the vibrations very easily. The cast iron also provides better sliding properties, the friction would be less and the wear and tear of the cast iron would be less.

The steel material also has good damping properties, but the strength of steel is higher during the static and dynamic loading.

There are certain other metals, such as copper and aluminum which are also used in the construction of an automated system. In addition to these, there are certain non metals such as polymers, polycarbonate sheets and glass. These are mainly used to prepare the housing or the cover of the automated system.

Now, as far as the manufacturing or the fabrication of the automated systems are considered, let us consider the part 1, part 2, part 3 and part 4 are nothing but the bed base or the columns, the spindle head, the table carriages or the skin of the automated system. Now, as I mentioned we need to design them and fabricate in house.

For that purpose, we require the raw materials. From where are we getting the raw materials? We are getting the raw materials from the mother earth, from the nature. And the conversion of the resources available from the mother earth into raw material is basically being done by the mining and metallurgy branch of engineering.

We need to convert the raw materials into the final product that is required for our intended purpose for the fabrication of the automated system. To convert the raw material into finished or a semi finished product, we need to carry out certain operations. These operations are grouped together as primary forming operations and the casting operations.

The primary forming operations converts the raw materials into basic shapes such as rods, sheets and bars. The raw material which is available in the form that is fine to work with and use them for making the final product through, the other set of manufacturing processes can be directly proceeded. However, in certain cases we need to change the shape of the primary formed components.

For that purpose, there is another set of operation need to carried out. And these are called as the secondary forming operations in primary forming. We are getting roll sheets extruded bars and rods, if it is fine to use the sheets, as it is for making the final product, for making the housing it is fine. But, we need to carry out certain operations on the sheets.

For example, we need to have some holes, some notches on the sheet. For that purpose, we have to carry out another operation on that and that punching operation, the notching operation is nothing but the secondary forming operation. If we are having bars, we are using the bars directly for the welding operation; we want the bent bars for our construction purpose. Bending operation is the secondary forming operation. Some parts need to be manufactured of the required size and shape by using the casting operation. But, the casting operation will not be providing us a good quality surface finish. The surface may have the dust, dirt and the surface may not be as per the required accuracy.

For that purpose we need to carry out a finishing operation that we call the machining operation. The machined castings can be utilized to make the final product. So, friends we will see these manufacturing processes one by one at a preliminary level.

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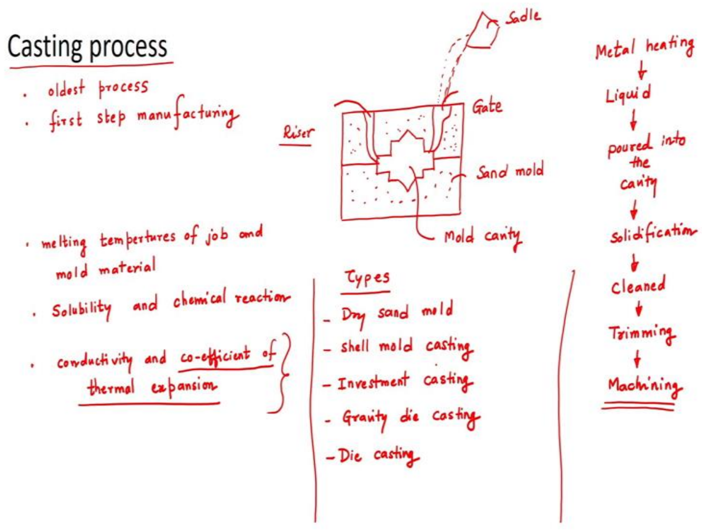

The first process is the casting process. Casting is the oldest manufacturing process and it is considered as first step in the manufacturing i.e. the first step in the manufacturing we have to carry out is the casting operation. The principle of operation is very simple. A mold cavity is made and the sand mold is a very typical and basic casting process. In the green sand casting, there is the gate which is the opening through which we are pouring the hot metal or the molten metal. There is the riser; used to allow the proper settling of the molten metal inside the mold cavity. Saddles are used to carry the molten metal.

We have to first heat the metal, it will be converted into its liquid state and the liquefied metal will be poured into the cavity. Then, that poured molten metal will be allowed to solidify and that solidified product will further be cleaned. Then, we are trimming off the gate and risers and then we are carrying out the machining operation. Ultimately after removing of the product from the mold cavity, either the mold can be reused if it is possible or in case of the green sand mold the mold is expendable. It is of only one time use. We have to discard it; we have to recreate another mold for the second item. Well in casting process we can achieve, whatever the size and shape that we want of the final product. However, we are changing the thermal properties, we are changing the material properties of the material. Whatever the thermal properties of the constituting elements of the casting will be changed, will be modified after the liquefaction and solidification process.

The designer or the process engineer should know about the melting temperatures; melting temperatures of the job and mold material, then solubility and chemical reaction between the job and the mold materials. In addition to this it is essential to know the thermal properties, mainly the conductivity and the coefficient of thermal expansion of the material of which we want to prepare the casting.

The coefficient of thermal expansion will decide the machining allowance. There are various types of casting processes that are used in the industry. These types are dry sand mold, shell mold casting, investment casting, gravity die casting, and die casting. And there are many other manufacturing processes as well of the casting.

The dry sand mold casting is a very typical casting process. It is used to manufacture medium to large size of casted products. Shell mold casting is used to manufacture medium size components. The investment casting process is used to manufacture small size parts at a mass scale. The gravity die casting and the die castings are used again to manufacture the metal components of medium size.

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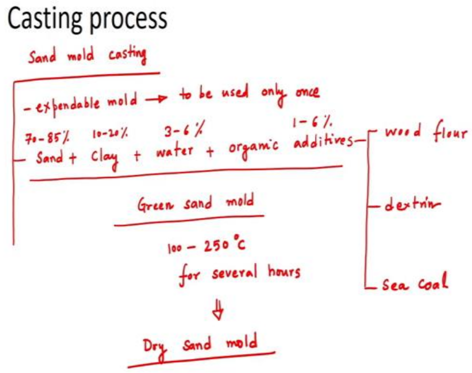

In sand mold casting we are using expandable mold, which is used only once. When the sand is mixed with clay and water with certain organic additives, we get the green sand mold. In general, the sand is in the proportion of around 70 to 85 %. The clay is about 10 to 20 % of the total volume of the mixture. Water is about 3 to 6 % and the organic additives are in between 1 to 6 %.

What are the various organic additives which are used? These are wood floor, dextrin and sea coal. This wood flour, dextrin and sea coal are used to improve the properties of the mold cavity and to give sufficient strength to them.

When we bake the green sand mold at temperature about 100 to 250 °C for several hours then, we are getting the dry sand mold. The dry sand mold has sufficient strength; it can withstand the fluid pressure during the pouring operation and the temperature of the molten metal inside the mold cavity.

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https://www.sodick.org/about-sodick/sodicks-technology/articles/machine-components.html

Now, let us see where these casted components are used in the automated system. In the slide, we can see the interior of a CNC machine tool. There are various structural elements that we can locate such as the bed of the system, the column. There are more elements which are mounted on the bed over which the table will be mounted. All these elements cannot be outsourced. We have to design them and we have to fabricate them in house.

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Forming process

- Plastic deformation -> desired size and shape
- fracture strength > Stresses > yeild strength
  - Tensile ✓
  - Compressive ✓
  - Bending ✓
  - Shearing ✓
  - Combination

Well the next manufacturing process is forming process. In forming process we are applying mechanical stresses on the work part or the raw material. And then we are getting the desired shape and size of the product. When we apply the mechanical stresses, there is a plastic deformation of the work part.

What kind of stresses can be applied?

We can apply tensile stress or compressive stress or shear stress or combination of these stresses. But, the stresses should be more than the yield strength of the material and less than the fracture strength of the material. This stresses will be generated by applying the forces. We can apply tensile or compressive forces or can apply forces which are generating the bending stresses, shearing or combination of these.

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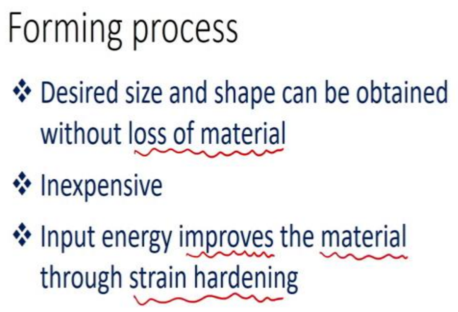

The peculiarity of forming process is that no material is wasted. Whatever the raw material is present, that would be reshaped by using the application of forces and as such, the process is inexpensive. There is no wastage in this process. Whatever the energy that we are applying during this process, will help to improve the material properties.

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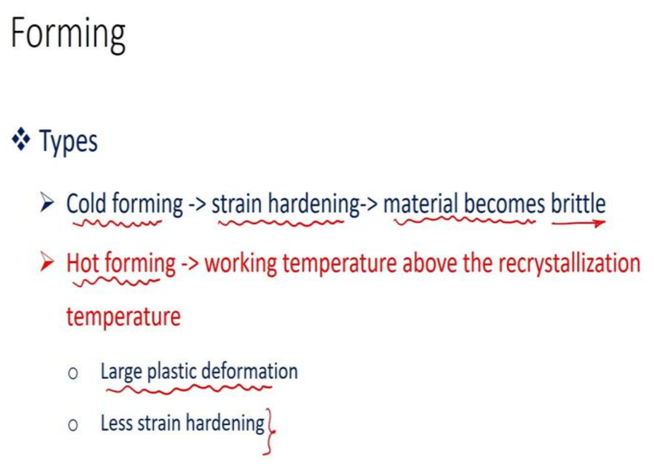

The strength of the material is getting improved during the application of the forces. During the application of forces, plastic deformation occurs and that is called as the strain hardening. There are basically two categories of the forming process, and these are based upon the application of the temperature and application of the heat energy during the process.

The first group or category is cold forming process. This forming process is occurred at room temperature. There is formation of strain hardening, the strength is getting improved. The improved hardness sometimes lead to increase in the brittleness of the material and such brittle material may not be useful for certain application, where the ductility is envisaged.

Where the ductility is desired, the next category of forming is useful i.e. hot forming process. Here the heat energy is applied and when the temperatures reaches above the recrystallization temperature, then the mechanical forces is being applied. During this hot forming process, large plastic deformation is obtained and the strain hardening is less.

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Now, let us see what are the various forming processes, which are used in the industry. These are rolling, forging process, drawing process, bending, extrusion, punching and blanking. All these are some of the basic forming processes. In addition to that there are many other process.

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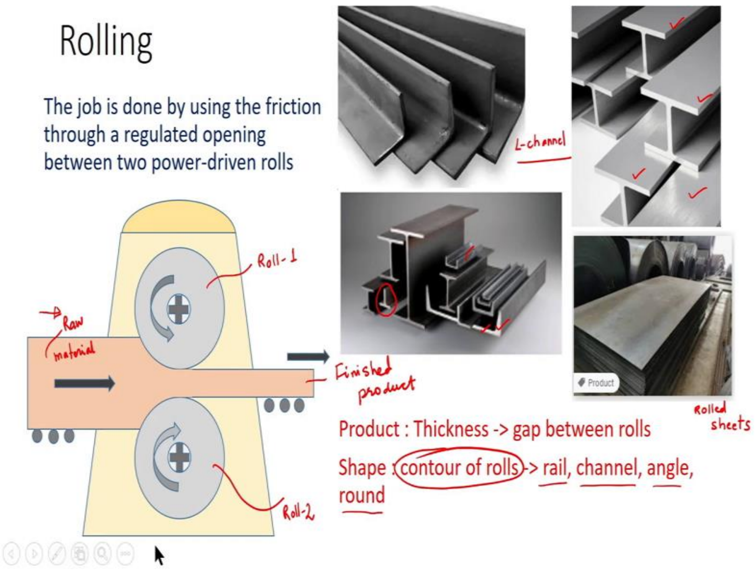

Now, let us look at the first process that is the rolling process. In the rolling process, we are having a set of rolls. Roll 1 and roll 2, these two rolls are power driven rolls and a constant gap is maintained between these two rolls. These two rolls are rotating simultaneously, but their direction of rotation is opposite. When we feed raw material in the form of a sheet, it comes in the gap between the roll 1 and roll 2 and it will be driven. The raw material will be driven due to the friction at the regulated opening between two power driven rolls. The rolls are pull the material inside and apply compressive forces. The compressive force generates the friction. And then, the friction will lead to plastic deformation resulting in the reduction in thickness of the raw material.

At last, finished product with reduced thickness is obtained. Now, this rolling process is not only used to reduce the thickness, it can also be used to manufacture various shapes as well, such as we can have the rail shape or various channels angles and even the round bars. To achieve these various shapes, we have to give the required contours to the rolls.

Instead of using flat rolls, we can have the contoured roll. Certain applications are there in the slide. They are roll sheets, eye channels which are often used in construction. In addition to that we can produce variety of angles and the C channels. In the slide, we can see the inverted T shape channel. All these channels can be manufactured by using the rolling process.

There are the other processes as mentioned: the forging process, the drawing process, extrusion process. In all these processes, we are applying the mechanical energy and are plastically deforming it. The forging process is hot forming process, temperature of the material is increased, it is being heated up and the temperature should go above the recrystallization temperature and less than the melting point temperature.

And then we are applying the mechanical loads over the material to get the required size and shape. Forging can be open die forging or we can use the die, to get the required size and shape that is called as the closed die forging.

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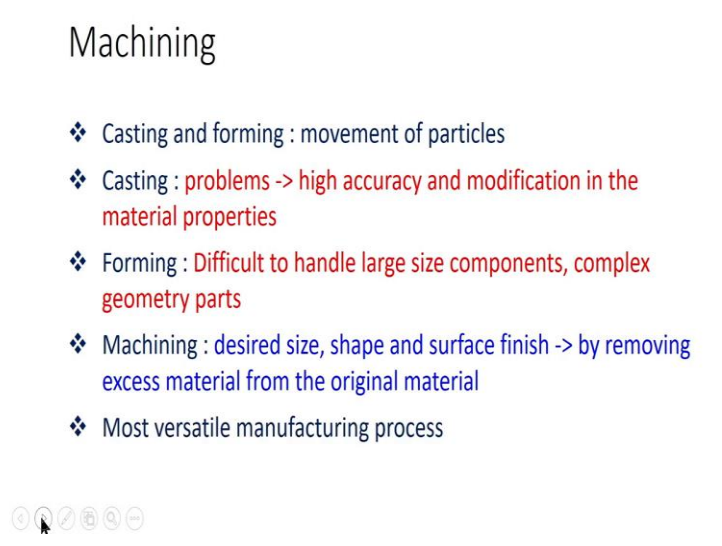

The next manufacturing operation is the machining operation. Casting and forming are the basic manufacturing processes; however, there is a movement of particles during this operation. The casting has inherent problems of high accuracy. We cannot achieve the accurate work part as desired, this is basically due to the shrinkages that is going to occur during casting re solidification process.

The re solidification is very complex phenomena. It is very difficult to control, for which it is quite challenging to get the required accuracy during the casting process. Well we are heating up the material and then cooling the material. Naturally there is change in material properties. Modification in the material properties may not be desired in certain applications.

The second operation is the forming; the forming is having inherent problem to handle large size components, very heavy components are difficult to handle during the forming operations. It is very difficult to generate complex parts. If we want to manufacture thin wall parts or the parts which are having complex geometries, those are difficult to manufacture during the forming process.

Some of these limitations of casting and forming process can be eliminated by using the machining operation. In the machining operation, we are getting the desired size, shape and surface finish by removing the excess material from the original material.

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Milling is the most versatile manufacturing operation. In the milling process a rigid tool is used. The strength of the tool is much higher than the workpiece. There is a relative motion between the tool and the workpiece, and the mechanism or machinery which is providing the relative motion between the tool and the work piece is called as the machine tool.

There is a primary cutting motion i.e. the tool is rotating at constant speed. And the uncut portion of the work piece is fed to the tool. As the tool comes into contact with the workpiece, there is a plastic shear deformation. In this way, we are removing the material in the form of chips. The relative motion of the workpiece and the tool in predefined path will generate the required shapes using the milling operation.

One very complicated shape is shown in the slide. This is the capability of the multi access CNC milling machine. Here we can see a turbine blades, these are manufactured by using multi access CNC milling machine tool.

Here the workpiece is inclined, we are moving the workpiece with respect to the tool or we may have a configuration where the tool is moving, we are giving the multiple degrees of freedom to the to the tool to get the required shape.

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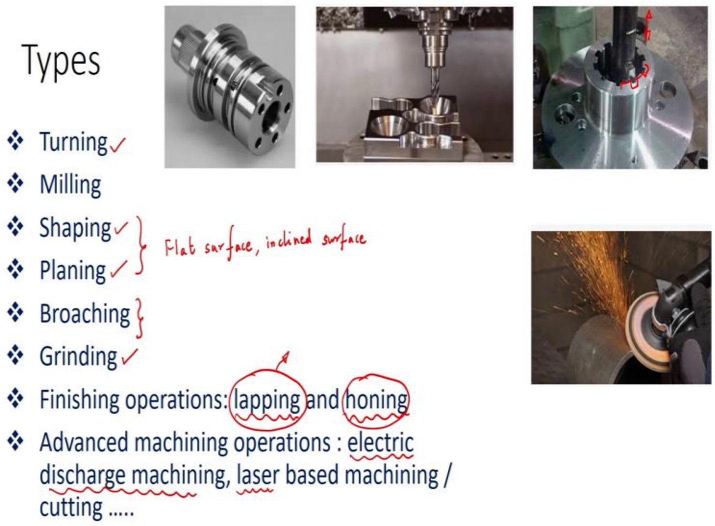

Well in addition to the milling process, there are various processes such as the turning. We carry out the turning operation on lathe machine. Shaping operation and planing operations are used to generate plane surfaces or flat surfaces. The flat surface may be inclined surface as well. Broaching is an interesting application. In broaching we are generating the spline or we can generate the keyholes in a circular part that we can see in the slide.

The tool is having teeth with gradual increase in their size. So, these gradual increased teeth are generating the required shape in the work part. Here we are having the reciprocating motion of the tool, in turning we are having rotary motion of the workpiece and translatory motion of the tool. In milling operation, we are having rotary motion of the tool and translatory or linear motion of the work piece.

In broaching operation, we are having the reciprocatory motion of the broaching tool and the workpiece is stationary. Grinding is a well known example here we are using the cutting tool in the form of particles. These particles are bonded together by using a binding material, the grinding material is utilized to remove the material in the form of very small chips and to get the required surface finish or to generate the required surface shape.

When we are using the loose abrasive particles for finishing operation, then that is called as the lapping operation. And when, we are using the abrasive particles in the form of sticks, then that we call the honing operation. The lapping and honing are the finishing operation. In lapping and honing, the tools are in terms of a fine particles or fine powder.

When we are using the unconventional mode of energy for material removal process, then the processes are called as the advanced machining process. Many a times it is very difficult to process the high strength material, say tool steel. For that purpose, the contact type mechanical processes may not be sufficient to generate the required surface finish and the shape. In this scenario, we are using electrical energy to remove the work material and to get the required size and shape or to cut the work part. Another example of the thermal based advanced machining process is laser, where we are using the photon energy to generate the heat energy. And that heat energy will be utilized to cut the material or to machine the material.

In addition to the thermal energy there are certain processes, where the chemical energy is used. Such processes are called as electrochemical machining operation. In certain cases, we are using the water to machine the work parts and that process is called as the water jet machining operations.

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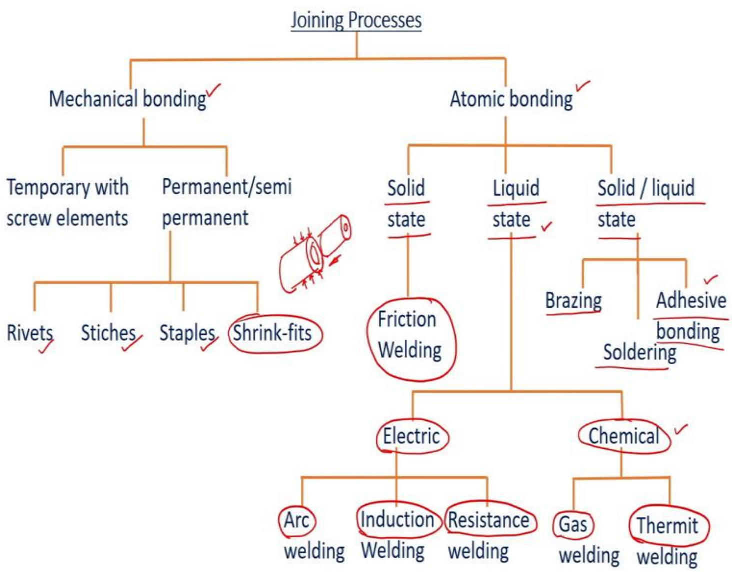

Well the next group of manufacturing processes that are often used in the fabrication of automated system is the joining process. We have seen the casting process, forming and the machining process, these processes are generating or fabricating the required work parts. But, in many cases it is not possible to fabricate a very complicated shape part; it is very difficult to manufacture complicated shape work parts.

We have to generate this complicated work part, by using the joining process. We have to divide this complex system into small parts and then we can join them together by using variety of process. In joining processes, we can have a variety of variants and these variants can be categorized based upon the type of bonding.

Either we can have the mechanical bonding of the work parts or we can have the atomic bonding. When the work parts are bonded together temporarily using the fasteners or the screw elements, that we call the mechanical bonding, its temporary mechanical bonding.

But, we can have the permanent mechanical bonding as well. For that purpose, there are many options available to us, such as rivets. The work parts can be stitched together, we can staple them together, we can use stapler pins. We can have the shrink fit. The shrink fit for example, if we want to fasten mechanically two tubes, the diameter of one tube is larger than the other tube, then we can insert the smaller diameter tube inside the larger diameter tube. And then, we apply the external force on the overlap region of the outer tube or the larger tube with the smaller tube. Due to application of the force we can have the shrink fit permanent joint.

In atomic bonding process the materials are bonded at atomic level. Such bonding can be carried out in solid state or we can liquefy the materials that are to be joined by application of energy. Such process is called as the liquid state atomic bonding. There may be a process, where solid and liquid both the states are present. That is a solid liquid state atomic bonding processes.

The liquid state bonding can further be classified into two groups. First is the application of electrical energy to liquefy the material. And, the second group is application of chemical energy to liquefy the material. When we apply the electrical energy we can generate arcs, that is very popular or very common welding manufacturing process i.e. arc welding process.

We can carry out the induction heating in between the two work parts and that induction heating will melt the materials and then, we can fuse them together. The heating which is generated due to the resistance between the flow of electric current between the two work parts is called as the resistance building.

In the other group that is the chemical based liquid state atomic bonding process, we are using the gases. The gas welding, oxy acetylene combination of gases is used to generate the flames and that flames are used to get the required fusion operation. Then, we can have a special welding process that is the thermit welding process, which is used for the on-site repair of the rails. Here also we are getting a chemical reaction. And that chemical reaction is generating the heat and that heat will be utilized to weld the parts together.

The solid liquid state welding group can further have variants, such as brazing operation, soldering operation or the adhesive bonding operation. In adhesive bonding operation, we are bonding the parts together by use of an element, that we call the glue or adhesive. By applying the pressure and temperature we can have bonding of two thin sheets. The strength of adhesive bonding is not that high as of the liquid state atomic bonding. In solid state atomic bonding process, we can join two different solid parts by using the friction process. We can apply the frictional force in between the two parts and then we can join them together.

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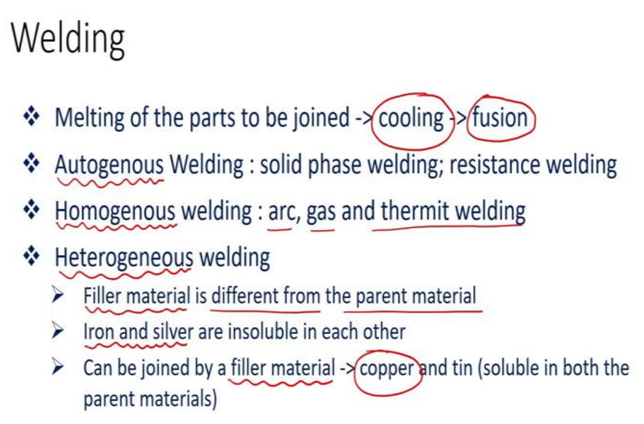

So, in typical fusion welding process, as mentioned, we need to melt the work parts that are to be joined and then allow them to cool down. Melting and then cooling will lead to solidification. When two molten parts are taken very close to each other, then fusion will occur.

There is an another categorization of the welding operation. And the first category is the autogenous welding. In autogenous welding, there is no external material that we are applying during the welding process. The two parent materials will be joined and in general, the solid phase welding process and the resistance welding processes are the examples of autogenous material.

But, if we take example of the arc welding process, there we are using an electrode. We might have seen a typical arc welding process at the fabrication shops. In the arc welding process, the electrode is the filler material, we are getting two work parts and there would be a gap between the two work parts. We are generating the arcs by application of the DC power source or AC power source. That arcs are generating the heat and that heat is melting the work parts.

In addition to the molten work parts that are to be joined, the electrode will also get melted and that electrode will get fused with the two different parts. The material of the electrode would be similar to the parent materials. When the material of the electrode is similar to parent material that process is called as homogeneous welding process.

Arc welding, gas welding and the thermal thermit welding are some of the examples of the homogeneous welding process. But, in certain cases it is not possible to use the similar kind of electrode for the joining operation, that variant is called as the heterogeneous welding operation.

In this process, the filler material is different from the parent material. The situation may occur when we are trying to join two different materials such as iron and silver, which are not soluble in each other. But, we need to join them, so to join such insoluble material; we have to use a filler material. The filler material should be soluble in both the parent material.

Here we can have an option of a copper and tin. The copper and tin both are soluble in iron and silver. So, we apply the heat energy, we melt the copper and that molten copper will be utilized to join the iron and silver.

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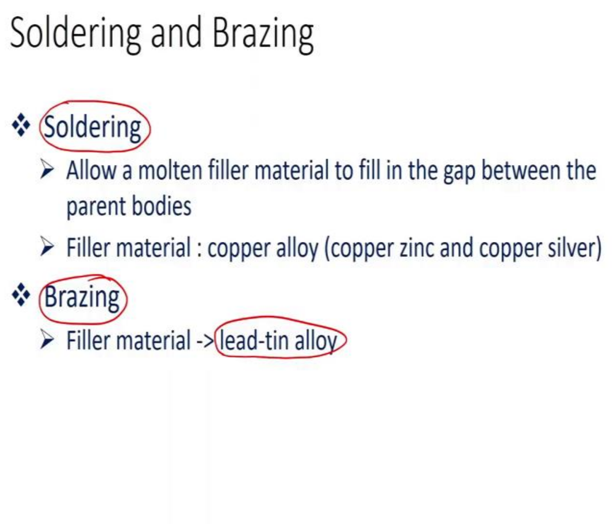

Soldering and brazing are the examples of the heterogeneous welding. When we use copper based alloys as filler materials to fill the gap in between the parent bodies, that process is called as the soldering operation. And if we use the lead tin alloy to carry out the heterogeneous welding operation, that process is called as the brazing operation. The temperature range of the soldering and brazing is less than the arc welding process, at lower ranges we are working during soldering and brazing operations.

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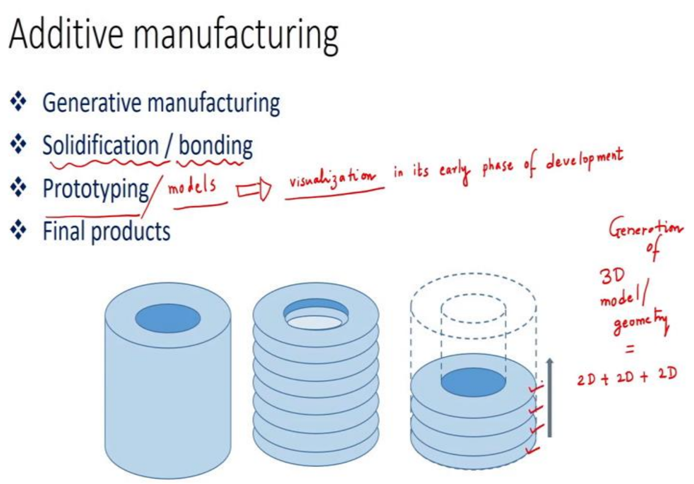

The next manufacturing process which is nowadays often used in the development of automated system is the additive manufacturing. The additive manufacturing is basically the generative manufacturing process, we are not removing anything from the parent material, we are adding the material to the parent material. And then we are building up the product.

In this process the work parts are generated by adding the material. That is why it is called as the generative manufacturing process. It basically comprises the solidification and bonding of the material. We are liquefying the material and then the material will be allowed to solidify. During the process of solidification, it will get bonded to the layer, it will get bonded to the other material.

The additive manufacturing is very useful in the development of the prototyping. The engineers are using the 3D printing or the additive manufacturing processes to develop the prototypes. And these prototypes and models are useful for the visualization of the product shape, in its early phase of development.

So, if we recollect the product life cycle, there is a function that we call the product conceptualization. To conceptualize the product, we have to visualize how the shape of the product will be looking like. To visualize that we can use the prototyping based on the generative manufacturing process.

But, nowadays we can also manufacture final products using additive manufacturing operations. In the slide, we can see a typical product that is to be manufactured using the generative manufacturing process. In the generative manufacturing process, the required geometry, would be converted into layers. And we are developing the final work part by joining these layers, by adding the layers one above the other.

In this process we are generating 3D model or the geometry by adding 2D planes or 2D work parts. In generating or manufacturing a 3D model, it is built by slicing its geometry into the finite number of layers and that layers are bonded together by using variety of method.

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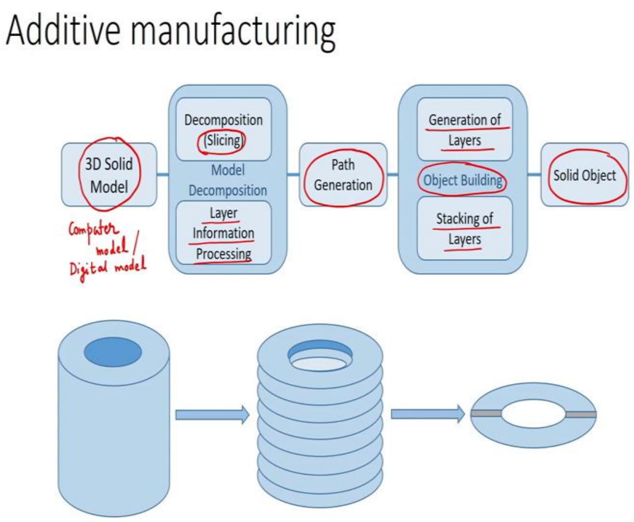

The process of building up this 3D models or 3D products can be seen in the slide. To get the final product, we need to first develop its computer model and this computer model is called as the digital model. The digital model will be decomposed or it will be sliced into finite number of layers, then the information about the layers will be processed and the path will be generated.

This path is nothing, but the relative motion between the tool in the generative manufacturing process and the work part. We will be seeing one of the example of the additive manufacturing in the later slides. The generated path information will be given to the additive manufacturing equipment, and the layers are generated.

And by stacking the layers above each other, we are developing the object. Thus schematically we can see the 3D object is sliced into number of the 2D layers. The information about the layers will be utilized to generate the path; the information about the path will be given to the generative manufacturing equipment.

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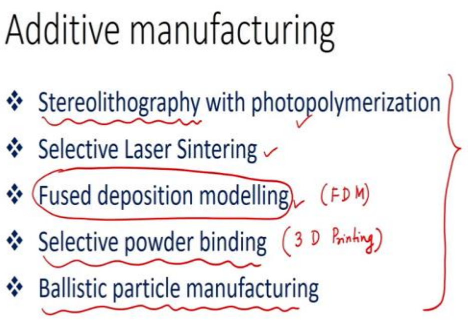

There are many variants of additive manufacturing operation. These are the stereo lithography with photo polymerization, selective laser sintering, fused deposition modeling (FDM), selective powder binding (3D printing) and the ballistic particle manufacturing.

The stereo lithography is the very first additive manufacturing process; however, the FDM is often being used, it is quite popular among the rapid prototyping applications of this generative manufacturing process.

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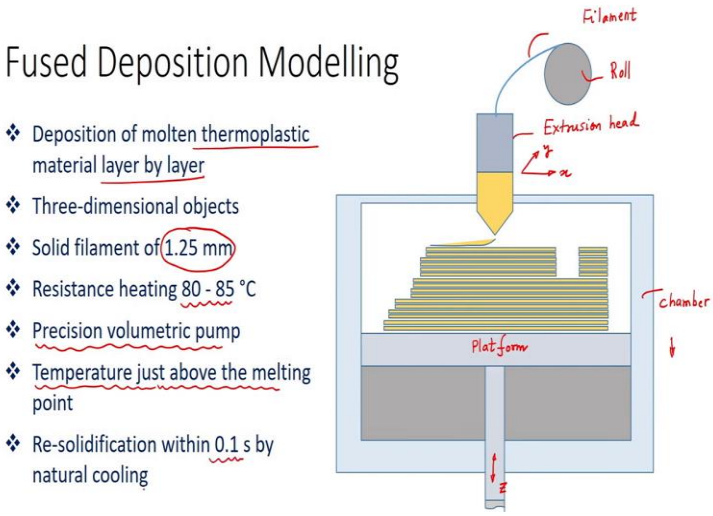

Well for our study we can have a look at the fuse deposition modeling process. In the slide, we can see the typical arrangement of the FDM.

The FDM process is carried out by depositing the molten thermoplastic material layer by layer. To deposit the molten thermoplastic material layer by layer, an arrangement can be seen on the slide. In this equipment, there is a platform, this platform is arranged in a chamber. It has a roll and this roll is having winding of filament i.e. the raw material filament.

Then the main part of this process is the extrusion head. The filament is fed inside the extrusion head, the extrusion head is hitting the filament and in its liquid state that filament will be extruded through the nozzle. And that extruded part would be put on the platform. The required deposition can be achieved by having the relative motion of the extrusion head with respect to the platform.

This extrusion head can be moved along x and y direction; however, the platform is moving along the z direction. As we move the extrusion head, we can deposit the required material on the platform. After generation of one layer on the platform, the platform will be lowered, it will be moved into the downward direction. After the generation of a layer, the next layer will be deposited on the previously deposited layer. And in this way we can generate the 3D models using the fuse deposition modeling. In general the thickness of this filament is about 1.25 mm, the heat heating would be carried out in between the 80 to 85 °C inside the extrusion head.

The extrusion head is also having a volumetric pump, which is precisely pouring the molten thermoplastic material through the nozzles. The deposition operation is being carried out at a temperature just above the melting point temperature. The re solidification time is very small i.e. 0.1 second.

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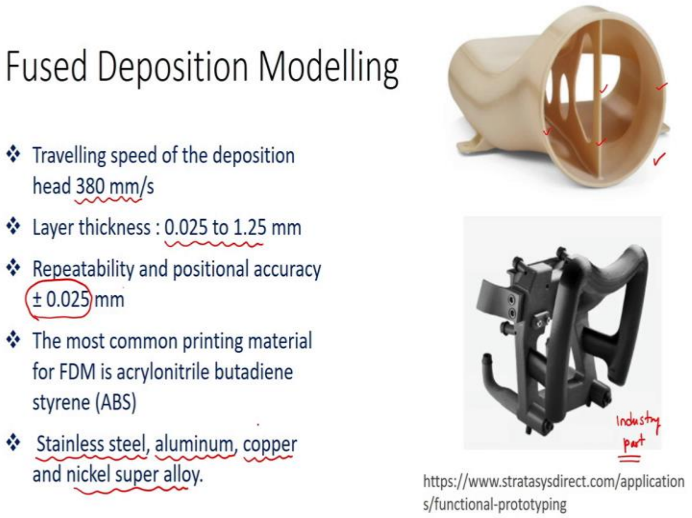

So, in the slide, some of the models which are generated by using that fuse deposition modeling process can be seen. Here you can notice that very complex shapes can easily be manufactured using FDM. We can also notice that, the thin parts can easily be manufactured. In addition to that, the industry part basically jigs and fixture part is manufactured by using the FDM process.

Some important parametric data can be seen in the slide. In general, the traveling speed of FDM is about 380 mm/s. We can have the layer thickness in between 0.025 to 1.25 mm. The FDM process gives us repeatability and positional accuracy about ±0.025 mm.

The most common printing material which is used in FDM is acrylonitrile butadiene styrene (ABS). But, my friends we can also utilize or we can use the stainless, steel, aluminum, copper or nickel super alloys to generate the 3D models using the FDM methodology.

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So, let us summarize this lecture. At the start of the lecture, we have seen various fabrication techniques. And then at preliminary level we have gone through the casting, forming, joining, machining and generative manufacturing processes. My friends, the detail analysis of these processes is out of the scope, you can refer the other courses or you can refer the standard textbooks available to study in detail about these processes.

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In the next week we will be studying the sensor technology, various sensors which are required in automation systems. And we will also see their principle of operation the constructional details and its applications. So, with this I conclude this lecture.

Thank you very much.