Metal Additive Manufacturing
Prof. Janakranjan Ramkumar
Prof. Amandeep Singh Oberoi
Department of Mechanical Engineering and Design
Indian Institute of Technology Kanpur
Lecture 02
Additive Manufacturing Process: Classification and Challenges

(Refer Slide Time: 00:18)

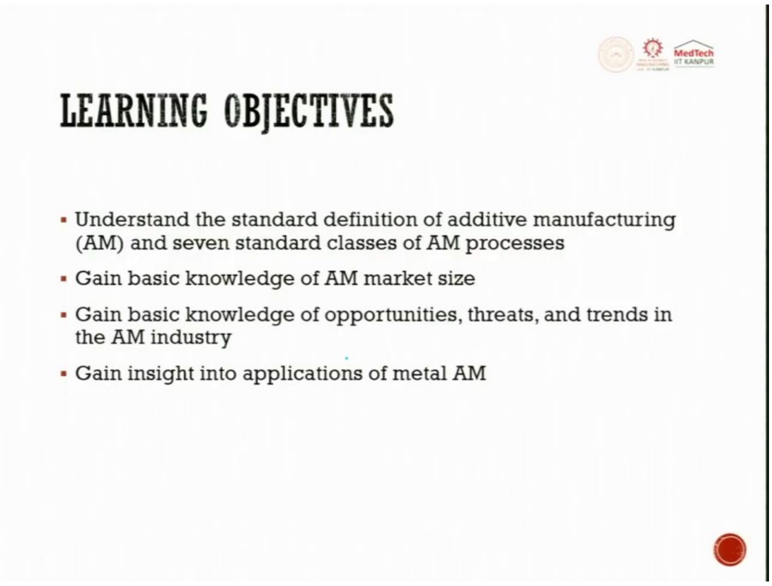
Welcome to the next lecture on Additive manufacturing process, classifications and challenges.

(Refer Slide Time: 00:29)

In this lecture, we will try to cover a few topics which is an extension to the introductory lecture. First, we will try to cover a long-term game changer additive manufacturing. Next, we will try to see classifications of additive manufacturing which is by and large now frozen. Then, why metal additive manufacturing? Then, some of the current and future estimation of additive manufacturing which is in terms of metal with respect to market size, then we will see applications of metal additive manufacturing in various sectors. And finally, we will also see the challenges and opportunity.

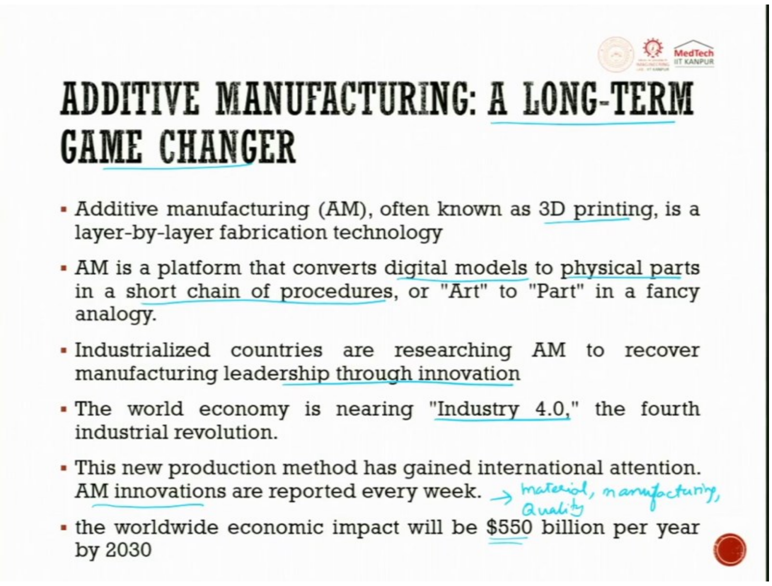
The content talks about what the additive manufacturing has achieved, but, when we look at the challenges and opportunity, you will see many more to come which are futuristic and open for young minds like you.

(Refer Slide Time: 01:30)



The learning objective in this particular lecture is going to be, understand the standard definitions of additive manufacturing and 7 standard classes of additive manufacturing process. Tomorrow, if somebody comes and places a product or a part in front of you, and asks you to decide which additive manufacturing process to choose, you should know at least the standard classes of additive manufacturing. Then gain basic knowledge about additive manufacturing market size. Then gain basic knowledge of opportunity, threat, and trends in additive manufacturing industry. Finally, gain insight into the application of metal additive manufacturing.

(Refer Slide Time: 02:20)



Additive manufacturing a game changer-this is going to be long term, why because it is going to be part of sustainable manufacturing. When we talk about sustainable manufacturing, we look at minimum energy which you have used in producing the part or the product. Today, when we are talking about the SGD goals, the long term game changer is going to be additive manufacturing.

Additive Manufacturing often known as 3D printing is a layer-by-layer fabrication technology. So, here we are trying to add material layer by layer or which is space by space or island by island, you join them to form a final part. Here, the energy will be reduced to a large extent in manufacturing. It is not only the energy, but also, the usage of coolants and pollutants which are involved in the process are also reduced.

Additive Manufacturing is a platform that converts digital models to physical part in a short chain of procedure. So, here whatever idea you have drawn, you can convert that drawn idea into a physical part in additive manufacturing.

Earlier what we used to do is we used to draw a part, then we used to take the part convert it into a manufacturing drawing, then release the manufacturing part drawing to various departments like for example constant volume process department, they start doing the manufacturing drawing, look into each of the manufacturing drawing and then they also try to take it to the machining shop trying to understand how do we assemble it and then produce it.

But, here from the digital model directly or converting into a physical part in a short chain of procedure.

When we are looking at new product development, the product life cycle, the prototyping phase takes a long time, which is now shrunk down to 10 percent. Industrialized countries are researching AM to recover manufacturing leadership through innovation. When this additive manufacturing is coming into existence, there are leading manufacturing companies who are putting time and effort in converting the normal procedure into additive manufacturing and in additive manufacturing, they are also trying to modernize the part as well as the process to meet to their requirements.

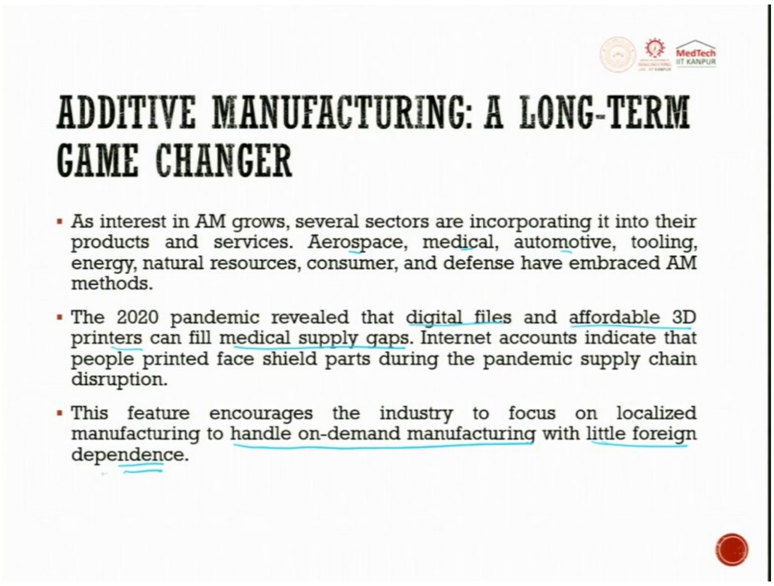
There, there is a lot of scope for innovation. When world is talking about industry 4.0, it is very easy in this additive manufacturing machines to integrate this industry 4.0 concept and try realizing the final part which is quality assured.

This new production method has gained international attention. AM innovations are reported every week. Every week, we have new AM innovations in terms of material, in terms of manufacturing method and in terms of quality assurance and quality assurance. So, more and more techniques are coming into existence.

And we in this particular course are more focused towards metals. In metal, they are looking at new and novel alloys, for exotic material properties they are looking at manufacturing process, reducing the consumption further more manufacturing methods are thought of and here when we talk about manufacturing methods, we are thinking of high quality, higher speed and assured output, and lot of innovations are happening. Topology optimization is one thing which is happening in the CAD itself.

The worldwide economic impact will be around about 550 billion dollars per year by the year 2030. By the year 2030, slowly the subtractive process will be removed and this additive manufacturing process which is a game changer will come into full extent.

(Refer Slide Time: 07:09)



As interest in AM grows, several sectors are incorporating this AM into their basic manufacturing in particular aerospace and medical, automotive, they are 3 major people who are spending a lot of money investing in the game changer additive manufacturing. 2020 pandemic revealed that digital files and affordable 3D printers can fill medical supply gaps in terms of masks, in terms of face shield, in terms of oxygen concentrator fittings, they were all designed and developed during the peak pandemic at every residence, internet accounts indicate that people printed face shield parts during the pandemic supply chain disruption.

This feature encourages the industry to focus on localized manufacturing to handle on-demand manufacturing with little foreign dependence. So, here 3D printing is going to give a big change to depend on the local market rather than depending on the foreign market. So, here the innovation in terms of product development for those products process used will be AM.

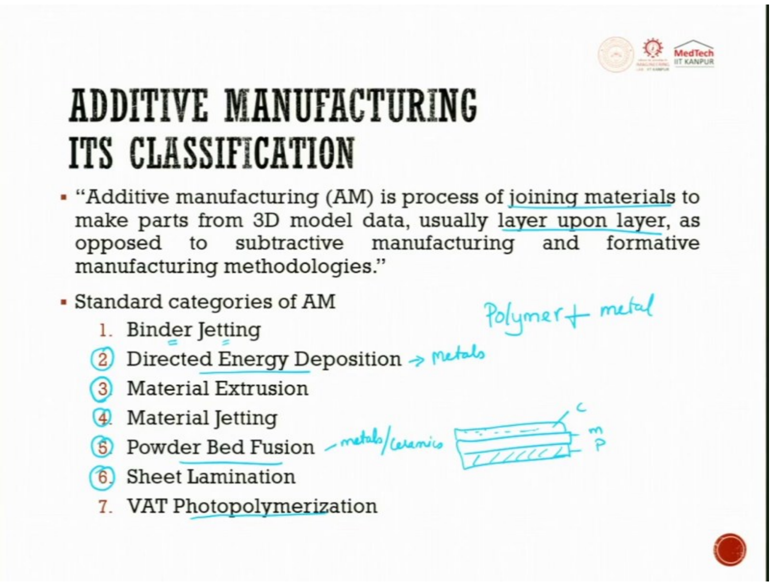
(Refer Slide Time: 08:39)

When the skill gap is a key barrier to the adoption of AM in industry, AM based courses are now your hotcake, they have been added in colleges and schools and university curriculum in a free way. This paradigm shift requires knowledge on AM principle, technology and software and efforts are undertaken to integrate these into an educational platform.

When we talk about the school level innovation which government of India is taking, they have introduced this additive manufacturing as part of Atal innovation labs for schools and colleges.

And now we are trying to introduce it as a basic course or a basic process to all students in the university to know a little bit about additive manufacturing. We anticipate in the near future that, like we have a 2D printer at home, color printer or your computer printout whatever you take, in the similar manner, every house will have a 3D printer for printing their own products and food in particular.

(Refer Slide Time: 09:58)



When we talk about the classification, first we will try to see definition for additive manufacturing. Additive manufacturing is a process of joining material. It can be polymer, it can be metal, it can be ceramic, it can be an alloy, it can be a composite. Joining of material to make parts from 3D Model data usually layer upon layer as opposed to subtractive manufacturing and formative manufacturing method.

So, for layer by layer joining of material, is it necessary that if I have to choose only polymer? No, you can also have polymer and metal hybrid manufacturing process. For example, you can start doing functionally graded material, 1 layer of polymer, 1 layer of metal can be done and 1 layer of ceramic can be done.You can have a blunt, you can have independent layers to functionally graded to meet the customer requirement.

If you want to do all these things in subtractive process, it is next to impossible in a cost-effective manner. For a flat surface, still you can try. If you want to do for a complex internal surface, it is next to impossible.

So, when we look into the categories of additive manufacturing or classifications of additive manufacturing, these are the 7 basic classifications.

One is Binder Jetting. As the name itself says, there is a binder which is used for consolidating either the powder or the layer and that which is getting ejected in a jetting manner. So, the binder can be a polymer, the binder can be the material originally you want to print it can be like that.

Next is directed energy deposition, DED. This method is very common in metals and ceramics also. People are trying to develop new process, but this is a very common process, which is used for metals.

Next is Material Extrusion, material extrusion is generally used in a form of a wire, this wire is used for depositing it layer by layer and then joining it, the material used predominantly is polymer. Today we have in this polymer blundered or mixed with ceramic and metals, which are extruded through the nozzle to produce the output.

The next one is material jetting, which I have already explained in binder jetting. Binder here is only adhesive or a polymer. Material here is the final material what you want, you try to do that material in a jet fashion through a nozzle to get it out.

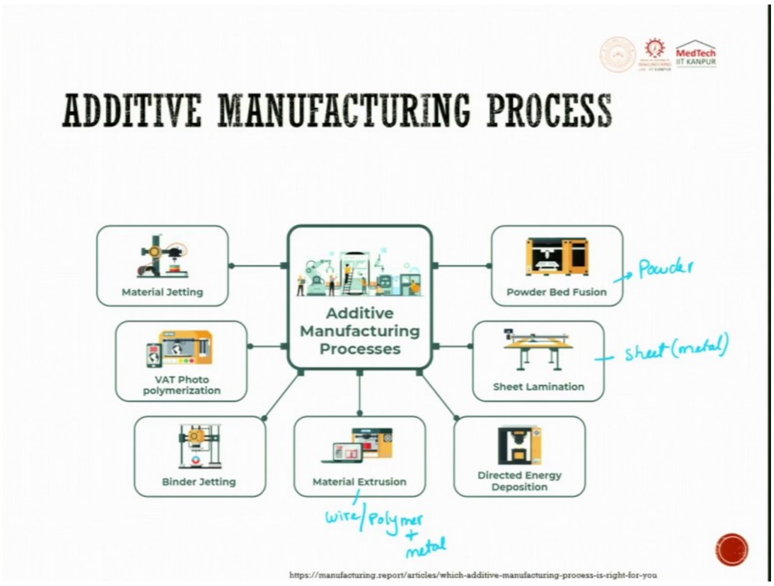
Then we have Powder bed fusion, again this is commonly used for metals as well as ceramics. So, here the powder is dropped and then we mix it with a binder or we try to melt the powder and join the powder. So, powder bed fusion is the next classification.

The last 2 are sheet lamination which is used for the starting material is a sheet and where we use ultrasonic welding process or we try to use laser for cladding process and then we try to join. So, these things are called as sheet laminate and then VAT is as it name says photo polymerization, is exhaustively used for polymers.

So, here in which we try to use light to cure a spot. Several spots joining together to form a line layer to produce the output. So, by and large when we try to look into metals, we will be looking into classification 2 in detail, 5 in detail, sometimes 4 very little 6.

Today, the classification 3 is also very commonly used for metal printing. So, 2, 3, 4, 5, 6 classifications will be exhaustively used for metal additive manufacturing.

(Refer Slide Time: 14:42)

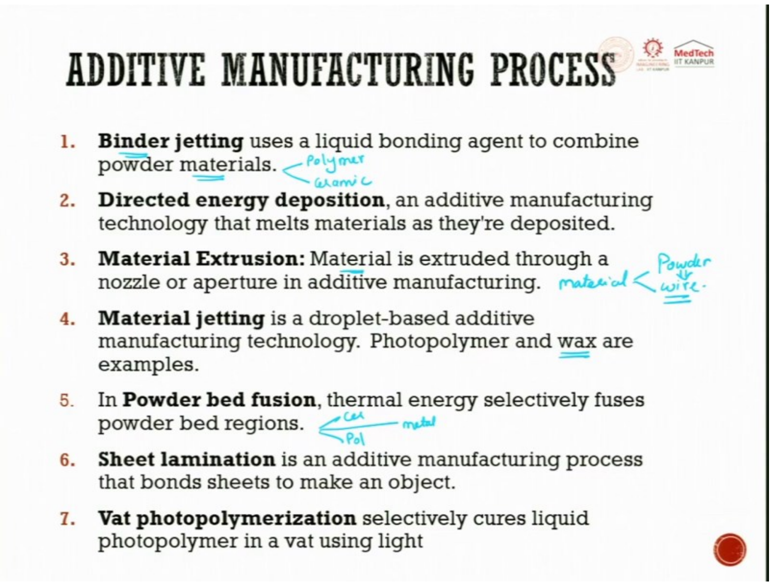


So, whatever classification we have seen, I have just put in a pictorial form, so that you can remember it very nicely. So, this is material jetting, where the material can be a wire, it can be a liquid form, they drop and then they get deposited.

VAT is polymer-based binder jetting. A binder is drooped down wherever the material has to be joined, it is binder jetting. Then we have material extrusion, directed energy deposition, sheet lamination and powder bed fusion. So, as the name indicates itself the starting material is a powder, here it is sheet, sheet is generally of metal only.

Polymer sheets are there, but by and large we do for metals, metal extrusion again, it can be a wire or it can be a polymer blend with metal. So, these are the basic classifications for the additive manufacturing process, this is common for metal, polymer and ceramic.

(Refer Slide Time: 16:08)



So, binder jetting is use a liquid bonding agent binder, binder means an adhesive. So, you play with a property of the adhesive, so, viscosity is controlled and then you try to drop at the place where you want the material to join, agent to combine the powder.

So, this can be of 2, it can be a polymer powder it can be a ceramic powder also. So, what people do is they use binder jet, make a ceramic part and this part is called as the green part. Then the green part is put for heat treatment, then it becomes a final part so, they use these two.

Directed energy deposition is an additive manufacturing technology that melts material as they are deposited. So, it is like as though they are coming through the tube, the powder comes and then the powder is exposed to a flame and that flame or heat will try to melt the powder and deposit the powder. Assume it is something like a bullet gun. So, you put a bullet inside a pistol and then you fire.

So, the bullet comes out and when the bullet is exiting out you apply a heat there. So, the bullet melts and it travels with a velocity and deposits. So, that is what is directed energy deposition. This is for basic understanding, we will see that in detail in the next lectures to come.

Material extrusion, here the material is extruded through a nozzle or an aperture in additive manufacturing. Material can be a powder or it can be a wire. So, generally when we say extrusion, it is always a wire. So, they will mix this powder also into a wire form. So, powder mixed into a wire form only is used.

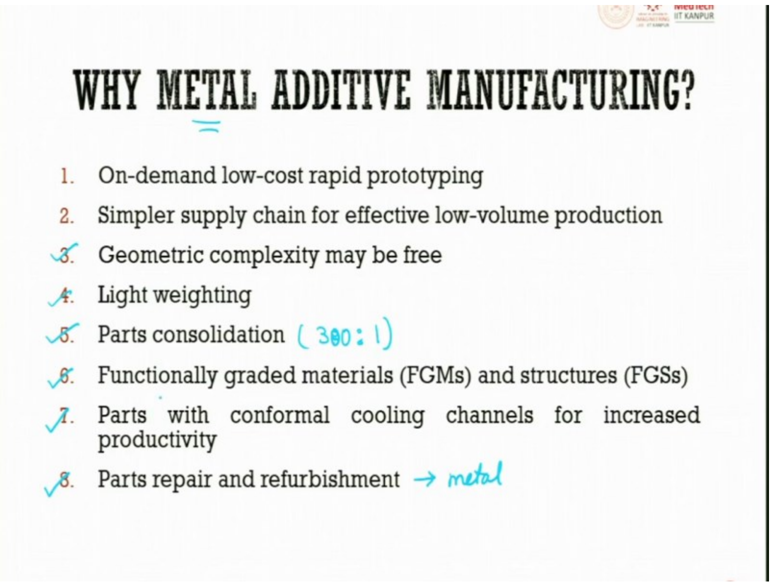
Material jetting is a droplet-based additive manufacturing technology, which is predominantly used for polymers and wax, the material is ejected out through a nozzle and deposited the final product when we want to make wax patterns, we use this material jetting, gold industry uses it for gold jewellery making.

The other big industry is for intricate parts to be made for aerospace application, the wax pattern is also used for intricate orgametric applications, they use this VAT material jetting process. This industry uses additive manufacturing very exhaustively.

In powder bed fusion, thermal energy selectively fuses the powder bed region. So, I told you ceramic, polymer and you have metal powder, you can use all these things. Sheet metal is an additive manufacturing process that bonds sheet to make an object, the bonding can be through ultrasonic welding or it can be through laser.

VAT as we have already seen, selectively cure liquid photopolymer in a vat using a light. A light will be always a laser or it can be a projected light.

(Refer Slide Time: 19:43)



Why metal amongst this 7, why exhaustively people talk about metals today? Because for metals, on demand low-cost rapid prototyping is possible. And today, we are trying to talk about rapid manufacturing. So, this on demand low-cost rapid prototyping for metals is coming up in a big way, there is a lot of application.

Supplier supply chain for effective low volume production can be used in additive manufacturing. So, metal is also, brought in very high. Geometric complexity may be free to make in additive manufacturing. And when we look at aerospace industry and auto industry, the number of parts is reduced and the part is made a single part and then it is put into real time use. So, complex geometry parts can be made. So, metal is exhaustively used.

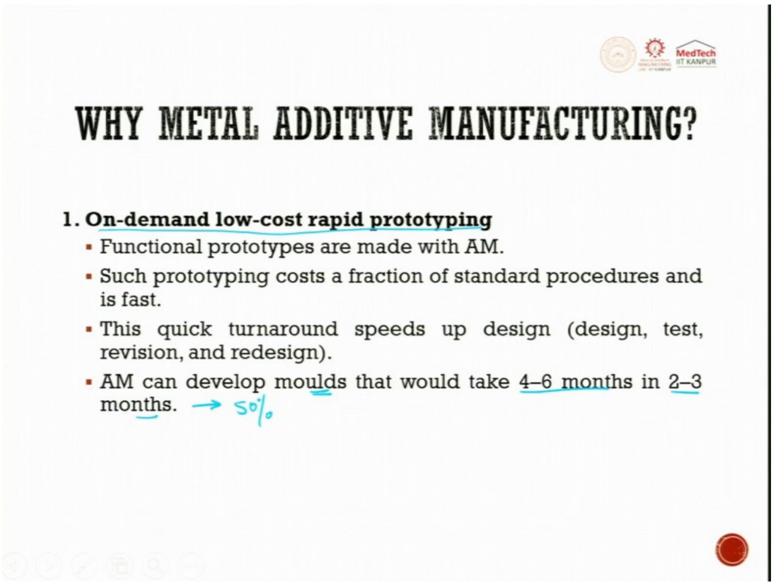
Light weight when topology optimization is applied and you still need very high strength, the part geometry is changed and you try to print the part with lighter weight to meet the requirement. Part consolidation in the complexity from 300 parts, have been completely converted into a single part in a turbine blade.

Functionally graded materials and structures can be easily made. Functionally graded material means layer by layer by layer there is a change. So, that means to say the top layer takes some heavy load, the bottom layer takes no load. So, it is like your I beam so, you have that functionally graded structure. Then parts with conformal cooling channels for increased productivity is used today in aerospace industry.

Part repairing and refurbishment is also, coming up where metals play a very important role. This point consolidation and functionally graded complexity are the very important points why metals are used in additive manufacturing, this I am trying to compare it with the metal based subtractive processes.

So, complex geometries can be made, lightweight can be made, part consolidation from 300 to 1 is possible. So, all small parts are removed, welding is removed. So, the entire thing is printed into one part functionally graded material and structures can be made. We will see some examples of conformal cooling in the later lectures to come.

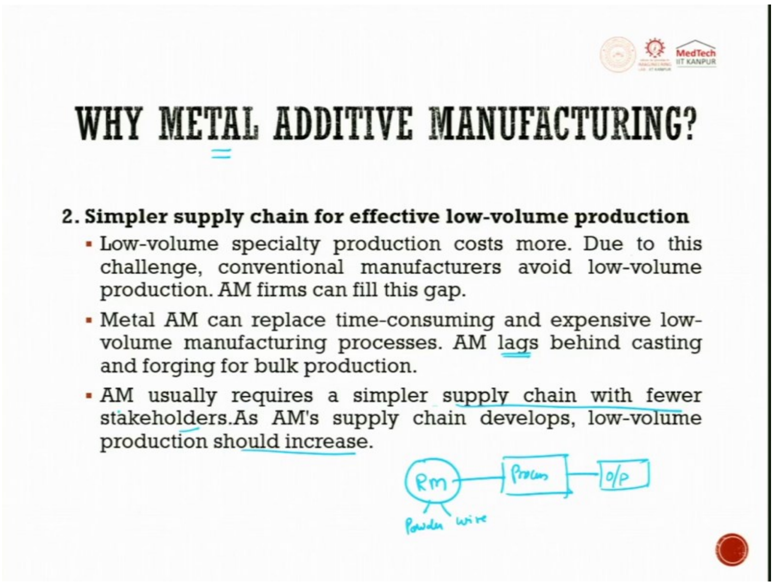
(Refer Slide Time: 22:26)



So, on-demand low-cost rapid prototyping functional prototypes are made with additive manufacturing such prototype costs a fraction of standard procedure and is fast this quick turnaround speed up design. Design, testing, revision, redesign all these things can happen. So, on demand low-cost rapid prototyping is possible. So, AM can develop molds that one point of time took 4 to 6 months now, it is getting done in 2 to 3 months.

So, it is almost 50 percent reduction in your mold manufacturing time and why especially when you make it by metal, whatever you print gets into rapid tooling and which can be used for fabrication.

(Refer Slide Time: 23:19)



The simpler supply chain for effective low-volume production, for low-volume, especially production costs are more. Due to this challenge, conventional manufactures avoid low volume production. AM firms can fill this gap. So, as far as metal is concerned, when we try to make casting process, metal forming process, if the batch size is 100 or 1000 then the cost becomes very effective. Otherwise, people always used to do it through machining route. In machining route also, for very low cost it is becoming very expensive if you have real intricate parts.

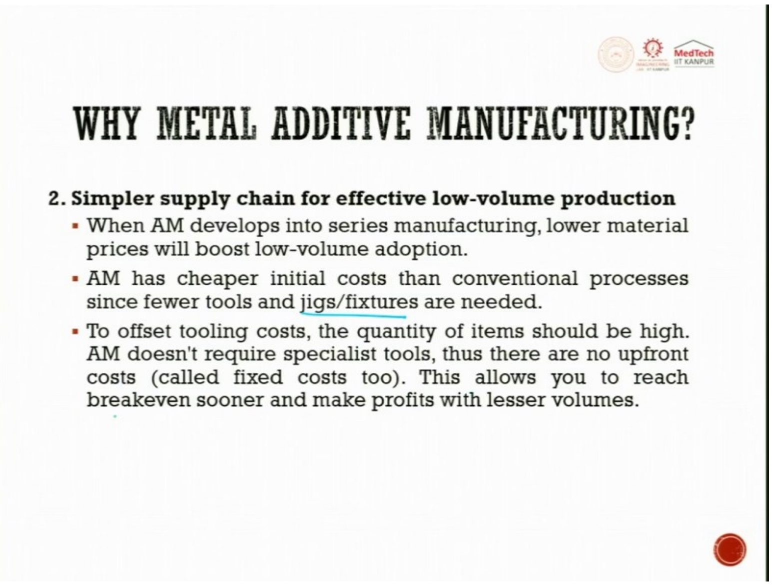
So, there that gap is filled by additive manufacturing especially metal additive manufacturing. Metal AM can replace time consuming and expensive low volume manufacturing process. AM lags behind casting, forging for bulk production. Even today AM is lagging, but since the concept of mass customization is coming into existence, people are trying to avoid the casting and forging process slowly because of the basic costings.

AM usually requires a simpler supply chain with fewer stakeholders. So, why because you need to have raw material which is your powder or a wire, then you get the output.

So, in the supply chain, all you need is only an AM raw material for AM, it can be powder wire, whatever it is. Then, process technology where in which we try to use some of the gases. So, you see here there are only 2 major players and then one skilled labourer, then you are able to get the output.

So, that is, as AM supply chain develops, low volume production should increase and the supply chain with fewer stakeholders are possible in AM as against the subtractive manufacturing process.

(Refer Slide Time: 25:29)



When AM develops into series manufacturing, low material price will boost low volume adoption. Initially 1 kilo of metal powder which was talked about 5,000 dollars today has come down to 10,000 rupees. So, 5,000 dollars is approximately 4 lakhs, today it has come down to 10,000 rupees. So, more and more vendors have come. So, the material price has brought down so, you get the output.

AM has cheaper initial cost than conventional processes as compared to metal forming. So, we use here small amount of or no tools jigs fixtures in additive manufacturing or maybe rarely we use fixtures for holding the part, the offset tooling cost, the quantity of item should be high, AM does not require specialized tools.

Thus, there are no upfront costing. So, when we try to calculate the fixed cost, it goes down drastically. This allows you to reach a breakeven sooner and make profit with less volumes faster.

(Refer Slide Time: 26:48)

Complex jobs which are shown here can start with a square cross section and end with a circular cross section, if you want to manufacture this it is next to impossible starting with a square ending with a cross section of a circle and trying to have a smooth connect assuming that there is a fluid which is flowing inside.

So, if you want to manufacture such complex parts, it is next to impossible if you want to make series of holes or sphere. So, here such jobs can be made. Geometric complexity may be free here. AM can make complicated shapes that other technologies could not even think of, allows geometry complexity to be cost effective.

Designed for use, instead of design for manufacturing is now talked about when AM comes into existence. So, we always talk about the concept- design for X, this X can be assembly, disassembly, measurement, quality, manufacturing, today we talk about design for use. So, this is more of mass customization.

Complex and organic part designed for performance may cost less, but not for all AM manufacturable. Overhanging features may produce residual stresses and flaws in metal AM therefore complexity may not be equal freedom.

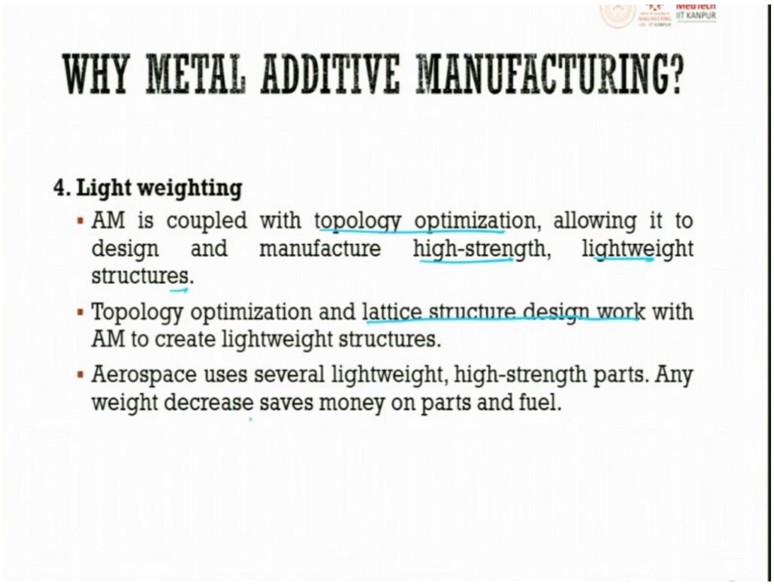
So, when we are involving overhanging features, what are overhanging features? So, you have an object, this is an overhanging feature, suppose if this overhanging feature is 10 times X than this and if it is heavier, So, then this will topple. So, you need to support such overhanging structures if you want to build features that may produce residual stresses and flaws in metal additive manufacturing. Therefore, complexity may not equal freedom.

(Refer Slide Time: 29:08)

Lightweight, as you see from this, we have reduced to this. So, you can see here that the weight is reduced. This is what is the clamp, which is used. Now, they have made the clamp little more complex such that it can try to take load. So, there are optimization based on shape, size and strength.

People do optimization for roughness also. So, the manufacturer makes greener and cheaper products. Lightweight components reduce energy utilization and fewer material use. Lightweight component reduces cost resource and environmental for both reasons, additive manufacturing is very much used and when you are looking from the strength perspective metal additive is very much used.

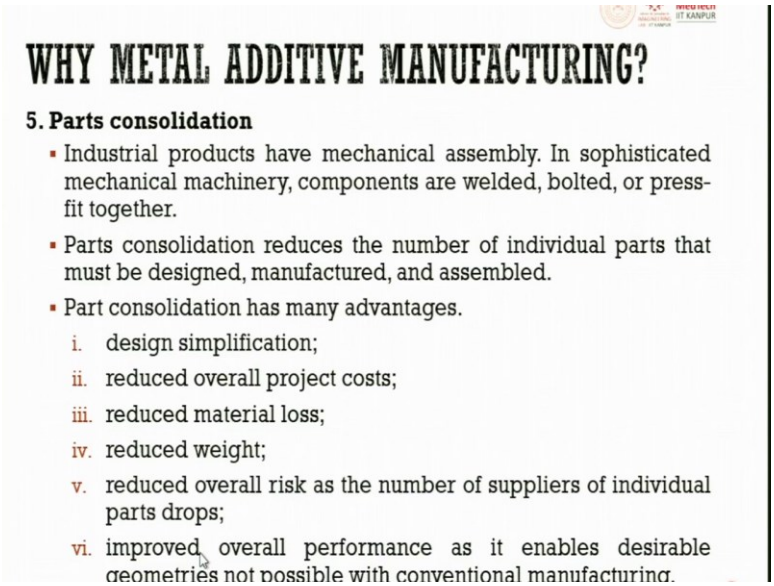
(Refer Slide Time: 30:19)



AM is coupled with topology optimization which I discussed allowing it to design and manufacture high strength lightweight structures, which is not so easy in the conventional route. We will be seeing topology optimization and lattice structure design work in detail in the forthcoming lectures.

Lattice structure design work with AM create lightweight structures, aerospace uses several lightweight high strength parts in the real time application, any weight read the degree, any weight decrease saves a lot of money both in automobile and aerospace, aerospace in particular.

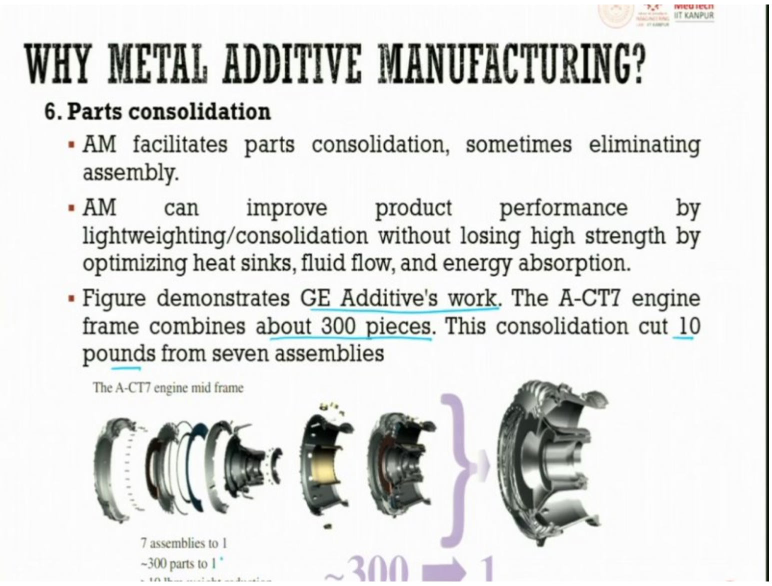
(Refer Slide Time: 31:00)



Part consolidation-the industrial products have mechanical assembly, if sophisticated mechanical machinery components are welded, bolted and pressed together. So, here in additive manufacturing, if you try to replace them, part consolidation reduces the number of individual parts that must be designed, manufactured and assembled.

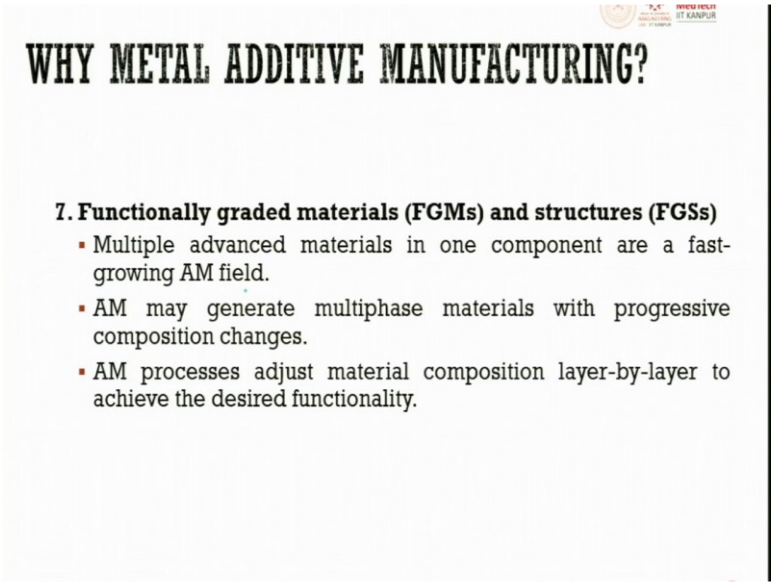
So, this manufacturing is fastest. To produce next is tooling. The part consolidation has many advantages, design simplification, reduce overall project cost, reduced material loss, reduced weight, reduced overall shrink risk, while reduced overall risk as the number of suppliers of individual parts drop, improved overall performance as it enables desirable geometry not possible with the conventional route. So, these are our major important things in part consolidation.

(Refer Slide Time: 32:04)



A simple example shown here is GE Additive manufacturing. They reduced 300 parts into 1, for their application because of that, they have cut down 10 pounds from 7 assemblies. So, now, so, if you do any weight reduction, it is going to be a huge saving when you are talking about aero industry.

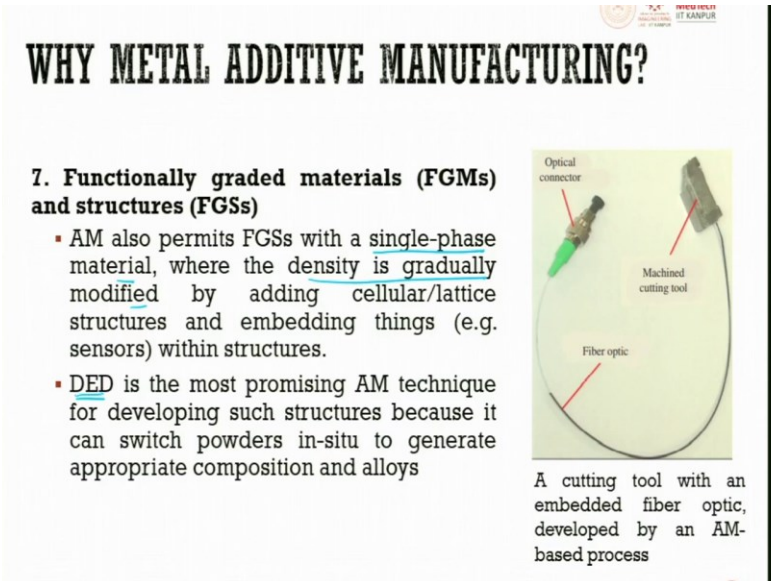
(Refer Slide Time: 32:34)



Functionally graded structures and functionally graded material, multiple advanced material in one component is fast growing AM field. Why are we talking about it? If you look at your skin in the body, it is functionally graded. In the top you have dead cells, then you have another set of cells, then you have the other set of cells. There is a gradiation and this gradiation tries to take care of multiple uses.

So, in the same way they wanted to try to develop materials, which can have several layers and which gives proper functional protection from the service condition. Multiple advanced materials in one component are fast growing AM field. AM may generate multi-phase material with progressive compositional changes. AM processes or just material composition layer by layer to achieve the desired functionality.

(Refer Slide Time: 33:33)

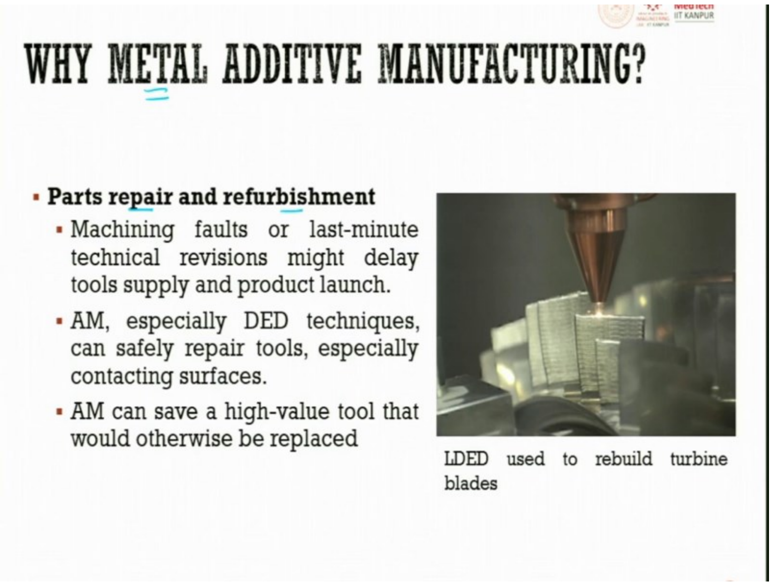


When we are talking about the strength, AM also permits functionally graded strength with your single-phase material, where the density is gradually modified by adding cellular/ lattice structure and embedding thing with structure. So, here you can see the optical connector. So, you have fiber optics, this gets integrated into your machined cutting tool.

So, here you have this with a single-phase material, where the density is gradually modified. The direct energy deposition or directed energy deposition is the most promising additive manufacturing technique for developing such structures because it can switch powder in C2 to generate appropriate composition and alloy.

So, DED we will study in detail it is the metal-based process where it is exhaustively used the cutting tool with an embedded fiber optic developed by an AM based process. So, here we are talking about functionally graded structures.

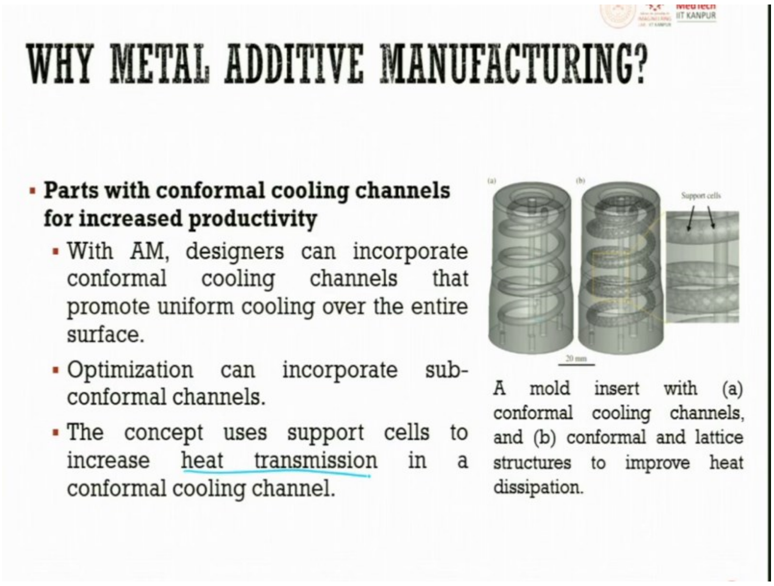
(Refer Slide Time: 34:54)

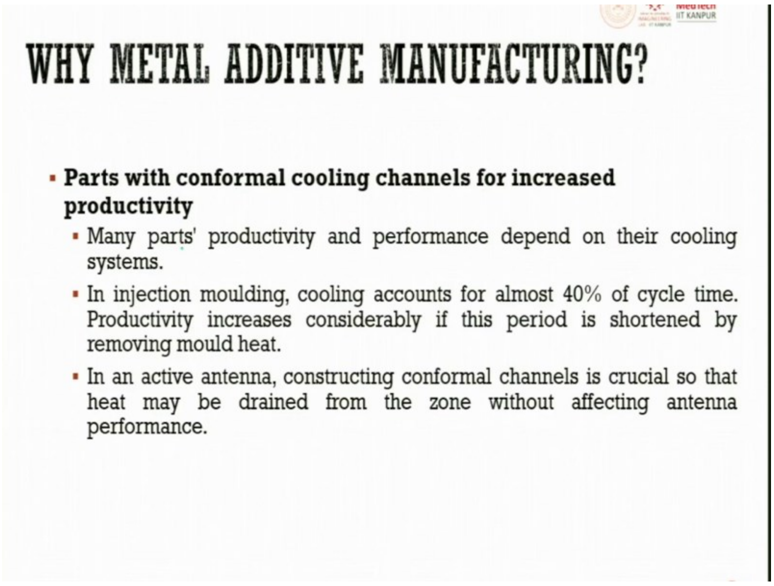


Repair and refurbishment, repair in that die and some small edges if they are repair. So, now what we do is we try to add material at that particular spot or gouge it out and do what earlier welding used to do now, they are trying to use metal additive manufacturing process to do so, here in which we can have firmer feature and we can have more of complex features, where powder is layered and the laser is passed by so, parts repair and refurbishment machining fault or last-minute technical revision might delay the tool supply and production launch.

So, where in which we use metal additive manufacturing for doing repair and refurbishment. AM can save your high value tool that would otherwise be replaced which is very common in mining industry, in aerospace industry and in heavy industry.

(Refer Slide Time: 36:08)



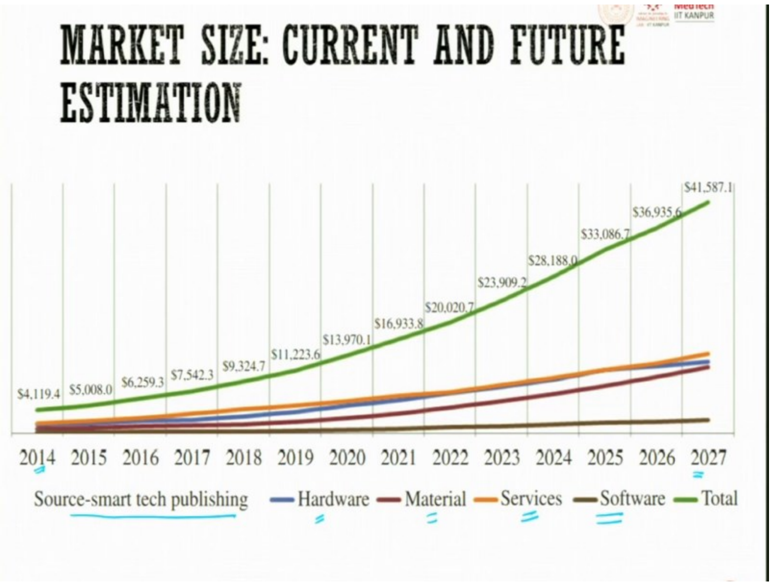


Parts with conformal cooling channels for increasing productivity. So, you can see some of the channels which are very difficult for you to fabricate in reality, these things are integrated while the part itself is developed, so, that they give a better cooling effect. So, many parts, productivity and performance depend on the cooling system. your laptop also depends on the cooling system.

The injection molding, cooling accounts for about 40 percent of the cycle time, productivity increases considerably if this period is shortened and remove heat in a quicker way. In an active antenna constructing conformal channels is crucial.

So that, heat may be drained from the zone without affecting the antenna performance. With AM, designers can incorporate conformal cooling channels that promote uniform cooling over the entire surface. Optimization can incorporate sub conformal channels, the concept uses support cells to increase the heat transmission in your conformal cooling channel.

(Refer Slide Time: 37:27)



When we start looking into market size, the current and future estimate this is exclusively taken for metal. So, you can see here from 2014 to 2027, if you see, there is a gradual increase in total. So, there is a need for software also to help in developing this additive manufacturing process to be more productive, service industries are exhaustively located using it.

Materials and hardware are some of the most important things which contribute for the total estimate of additive manufacturing in particular metal. In this lecture, till now, we have seen different classifications of additive manufacturing.

Then we went into why metal additive manufacturing and now we see the market size how is the market size keeps exponentially increasing over a period of time. In the next lecture, we will talk about applications and we will also try to see the opportunities and challenges with additive manufacturing in particular, metal based additive manufacturing. Thank you so much.