Laser Based Manufacturing

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Module # 06

Lecture # 20

Selective Laser Sintering and Selective Laser Melting

Hello everyone. I welcome you all to the lecture 3 of Week 6 of NPTEL MOOC course on laser based manufacturing. In this week we are studying the module on laser based additive manufacturing techniques. This week we have already studied the fundamentals of additive manufacturing as well as the stereolithography process.

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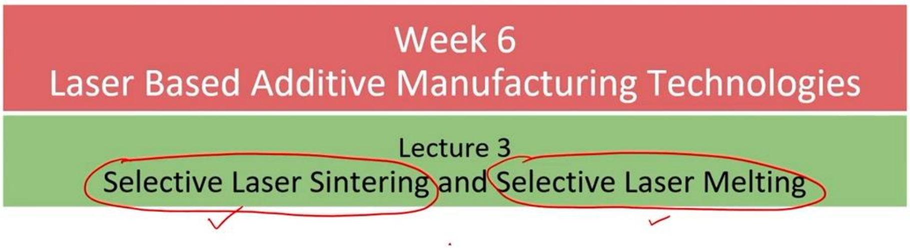

In this lecture we will be studying selective laser sintering and selective laser melting. Let's start. In the previous lecture we have seen stereolithography, which is basically used for manufacturing of polymer-based work parts. We have seen the process of photopolymerization and there are various approaches to carry out the photopolymerization using lasers. That is a vector-by-vector method and we have also seen the scanning method or the projection mask method. Well, when we look at the problems in the industry, it's not only the polymers that we have to deposit or it's not only we have to prepare the parts or products of polymers, we have to also make the parts made-up of metals or we have to make the parts of ferrous or non-ferrous metals. The photopolymerization based method which we have seen in stereolithography is not suitable to process the metals.

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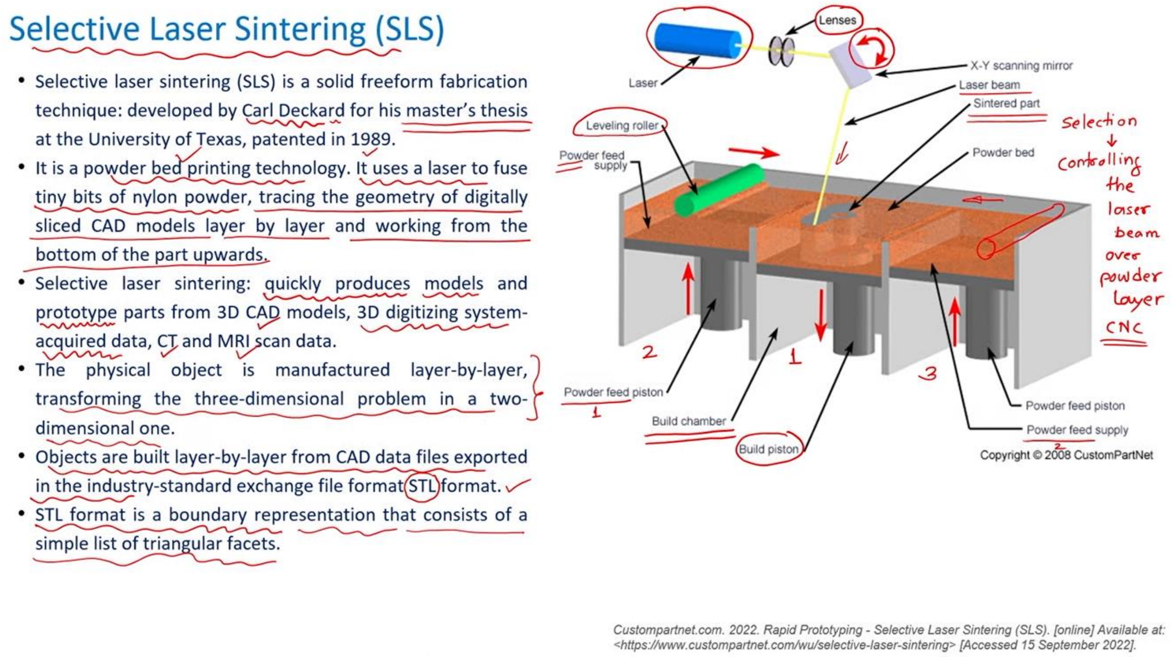

Here to resolve the limitations of stereolithography to process metals, Carl Deckard has developed the process that is selective laser sintering as far as his master thesis project is concerned, in the University of Texas around 1989. And he also patented this useful technology, and now it is very commonly used in the industry. It is very prominent contribution by Carl Deckard to the additive manufacturing technique.

SLS is a popular acronym of Selective Laser Sintering. This process is powder-bed printing technology. As the name suggests, we are using a powder bed and then we are generating the 3D objects-3D parts by selective sintering of various powder particles together by using lasers. That is a selective laser sintering. It uses a laser to fuse tiny bits of nylon powder tracing the geometry of digitally sliced CAD models layer by layer and working from the bottom of the path upwards. When we want to develop these parts, we are making use of tiny bits of the powder that is particularly the nylon powder and then we are carrying out its fusion together by using the sintering operation.

On your screen you can see the typical arrangement of this SLS equipment. You notice here we are having 3 chambers, this is the fundamental chamber, this is build chamber - here we are building the prototype or the part or the product, then we are having two feed chambers, this is powder feed station one or powder feed Chamber 1. This is powder feed Station 1 and we are also having Powder Feed Station 2 and that is the 3rd number of chamber in the entire equipment.

As I mentioned, in sintering operation we need the tiny bits, the granules of the material that to be laid upon, and then we are applying the laser beam energy. We should have sufficient material and that material should be in the form of powder, this is the powder and that powder we have to lay down over the work part. To carry out this operation, we are using a roller that is called as leveling roller. Then we need the usual arrangement of laser, laser producing equipment, a set of lenses, a set of mirrors to focus the laser beam on the work part. Then this is the laser beam that we are getting and this laser beam is carrying out the sintering operation of selected materials, that this selection would be done by controlling the laser beam over the powder layer by using a CNC based technology.

Fine, here you can see the laser beam is being applied over the powder and here again we have to develop the vector-by-vector method as well to scan the powder, to get the proper sintering operation done. And according to the laser beam energy applied, the powder is getting fused and then we are getting one layer of the powder. After getting a layer of powder, then the build chamber piston, this is the build chamber piston would be lowered by the distance of the thickness of the second layer that that we want. The CNC controller will actuate he build piston in downward direction by the amount of the layer thickness that we want. Once the build piston goes down, the roller will roll over the build surface and during the rolling operation the roller is laying down the powder over the already developed part or already developed layer, this layer has been developed and during the rolling operation the powder will get applied over the already developed part. The roller will come to this position, it will come to this position after the first operation done, then again the laser will come and it will apply the laser beam energy according to the vector given by the CAD and CAM software. And after that again there is movement of the build piston in downward direction by the amount specified by the controller.

Now the roller will move from right to left direction, it will move from this to this direction and during its movement to its home position again it will apply a layer of powder over the surface. In this way, now the third layer would be in action, it will be sintered and again the build piston will go down. These steps will be repeated in sequence and then we are building up the 3D part model by building up the layers on each other. In this way we are building up the 3D model by depositing layers over layers.

Selective laser sintering is producing models very quickly and it is again using its technology for prototyping the parts in a very faster rate from 3D CAD models. The input to this system is 3D digitizing system; it may be the acquired data in terms of 3D models, or it may be the CT-scans or MRI scan data. SLS is finding lot of applications in biomedical engineering in general to develop implants for human bodies.

Now how to develop the implants? To develop the implants, we need the geometric data of the body part that we need to make. In general the bones which are broken or the bone parts which are worn out which are to be replaced, these data is to be taken from the body part or the standardized bone parts data may be available. How to get this data? The data would be in the form of CT scans. CT scan is nothing but the computed tomography and based upon this CT scan data, then we can slice the model very easily or we can build the 3D model very easily. Moreover, even we can use the laser-based scanning as well for developing of the 3D models and that data also can be utilized. There is another input from the biomedical engineering and is MRI which we often use, it is Magnetic Resonance Imaging. By getting various images which are generated by magnetic resonance technology, we are generating the 3D models of the body part and these parts can be fed to the CAD technology and then the slicing can be done.

The physical object is manufactured layer by layer, transforming the three-dimensional problem into a 2-dimensional one. This is the very usual way that we already have seen in our previous two classes. The 3D model is converted into the two-dimensional model and then we are doing the 3D printing operation.

The objects which are built layer by layer from CAD data files are exported in the industry and that is the STL format (Standard Tessellation Language format), which we have already seen in our previous class. And this STL format is nothing but the boundary representation which consists of simple list of triangular facets which we have seen and by using the coordinates of the vertices of this STL Data file and the respective normals, we can generate these 3D parts by saying additive manufacturing technology in an easier way.

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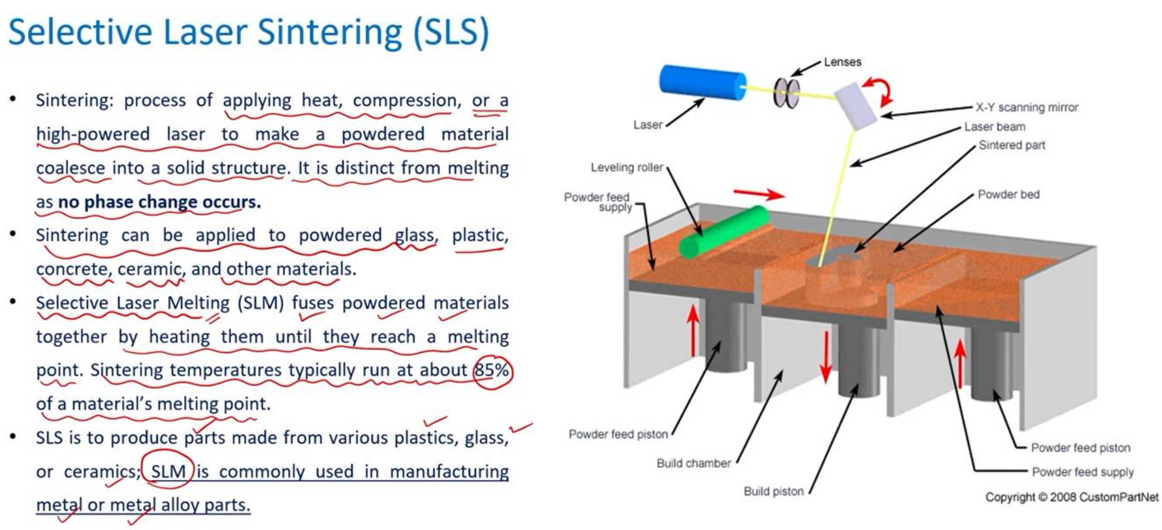

Sintering is the process of applying heat or compression or high-powered laser to make a powder material coalesce into solid structure. It is distinct from melting as no phase change is occurring. Here we are just making the necking of two atoms which are coming together, there is no melting of the grains or there is no melting of the material during sintering operation. Only two granules, or the molecules, will come into contact and there is a formation of necking due to the heating operation being done.

Here it is to be noted that the temperature is lesser than the melting point temperature that we need to generate, and if the temperature is more than the melting point temperature, we will not get the sintering operation done, that would go into the melting operation, even we may not achieve the required objective to have a strong 3D printed object in that case. We even may not get the proper geometric accuracy as well during the SLS operation. The temperature here should be lesser than the melting point temperature.

The sintering can be applied to glass plastics, concrete, ceramic and other materials. As I mentioned in SLM, that is a selective laser melting if you want to go for the melting operation, in that process, there is a fusing of powder material by hitting them until they reach the melting point temperature. The sintering temperatures are typically run at about 85 percentage of the materials melting point, we have to have a little temperature than the melting point during selective laser sintering, and that is about 85 percentage of the melting point temperature.

The SLS process is producing parts of various materials such as plastics, glass or ceramics. However, melting operation SLM is basically being used for metals or metal alloy parts, it may be ferrous metals or non-ferrous metals. SLM is being used for metals or metal alloys and SLS is being used for plastics, glass and ceramics material.

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Figure. Manufacturing of Nylon-polymer based products using SLS process

- Aerodynamic components, fans and small turbines
- Automotive industry: interior components
- Tubes, hinges, electrical housings and sports equipment

Formlabs. 2022. Guide to Selective Laser Sintering (SLS) 3D Printing. [online] Available at: <https://formlabs.com/asia/blog/what-is-selective-laser-sintering/> [Accessed 15 September 2022].

What are the various types of materials that we can produce by using the SLS? Here the applications are in aerodynamics, such as fans, small turbines are manufactured by using SLS. In automotive industry as well, the interior components are generated by using the SLS operation. Then tubes, hinges, electrical housings and sports equipment can be manufactured by using SLS operation.

On your screen you can see the parts which are manufactured by using the SLS. You just observe the complexity of these parts, their structural complexity, various features, surface finish which was easily possible by using the SLS process. Therefore the SLS is very common nowadays and it is very widely being used in the industry.

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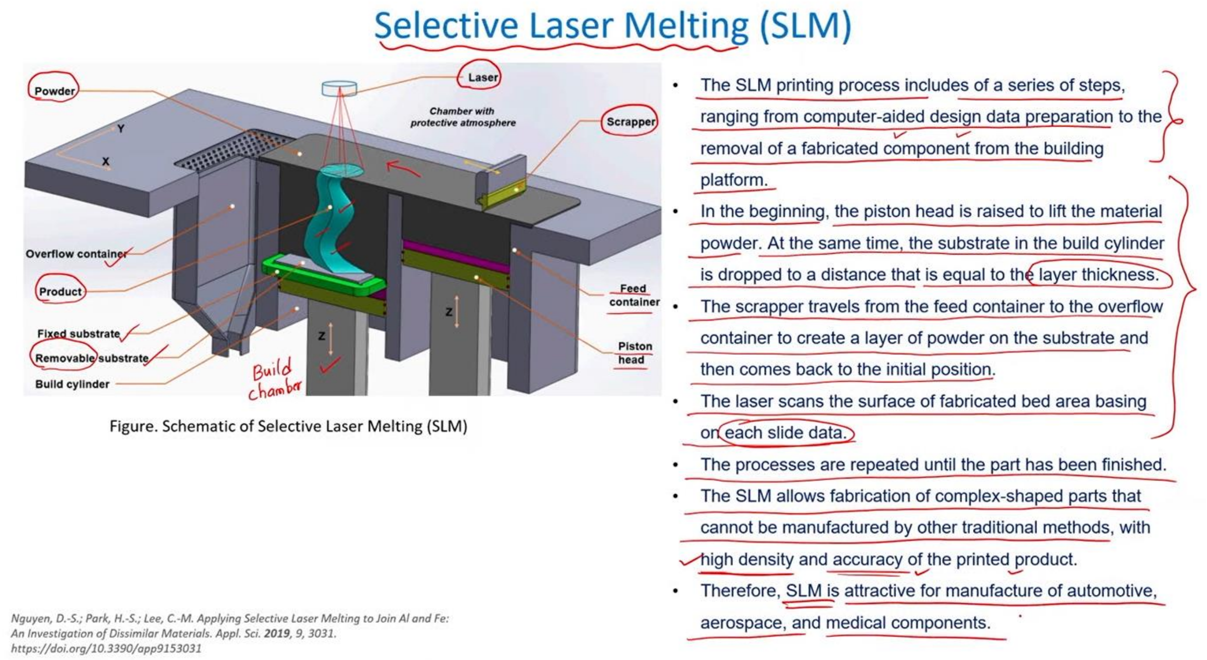

Fine, now let us study the next process that is SLM. It is selective laser melting operation. The SLM printing process includes a series of steps which are ranging from computer aided design data preparation to the removal of a fabricated component from the building platform. It involves many operations, many processes and these are to be carried out in sequence and these operations are starting from computer aided data presentation and then generation of the slices, applying or giving this information to the CNC controller, maneuvering of the laser, maintenance of the powder, so on and so forth and deposition, the melting operation and that to be carried out in a sequence and at the end we have to remove the fabricated component from the platform. All these operations are needed to be carried out in the given sequence to get the required part.

On your screen a schematic of the equipment, SLM equipment is there. You can notice here, again we are having the build chamber. This is the build chamber and this build chamber is having build piston and this is the feed chamber or feed container and it also has a piston. This is the powder which we need to melt, and then we have to create the 3D models. In case of overflow of the powder that has to be taken away, that can be reused as well, we need to have the overflow container. This is the product which is getting generated during this operation. There is a fixed substrate which is there on the build container. Then this substrate which we are removing during the operation, this substrate we are removing after the generation of the work part.

As usual, we need to have the laser beam and the laser beam is applied over the selected region of the metal powder and that would be melted and it will get resolidified. There is a scrapper that scrapper in earlier case we have seen the roller. Here it is a scrapper which is used to apply the layer of powder over the layers.

In the beginning, the piston head is raised to lift the material powder, at the same time, the substrate in the build cylinder is dropped towards distance that is equal to the layer thickness.

There is a moving, there is a getting down of the build cylinder in negative Z direction by a distance of layer thickness. The scrapper travels from the feed container to the overflow container to create a layer of powder on the substrate and then it comes back to its initial position. The scrapper moves in this direction, apply the powder and the remaining powder would be push inside the overflow container. The scrapper will come back and it will again regain its original position. The laser scans the surface of fabricated bed on each slide data. Based upon the slide data, there is a scanning of the laser. The processes are repeated until the part has been finished. These steps are repeated until we are getting the finished part.

The SLM allows fabrication of complex shape parts that cannot be manufactured by using traditional method. If you just look at this part, its complexity in terms of the geometry, then it is very difficult to manufacture this part by using conventional process. It is not impossible, but it is very difficult we have to use the multi axis CNC machining to carry out this operation and the operation would be very difficult but by using SLM it is very easy, we have to just slice the 3D model, give the data to the machine and machine is developing the work part layer by layer.

Moreover, when we talk about the traditional methods, it is difficult to maintain the density or accuracy of the part. But by using SLM we can have the required density and we can have the accuracy of the printed product or we can have better control of the density and accuracy of the printed product. Therefore, SLM is finding lot of applications in manufacturing of automotive, aerospace and medical components.

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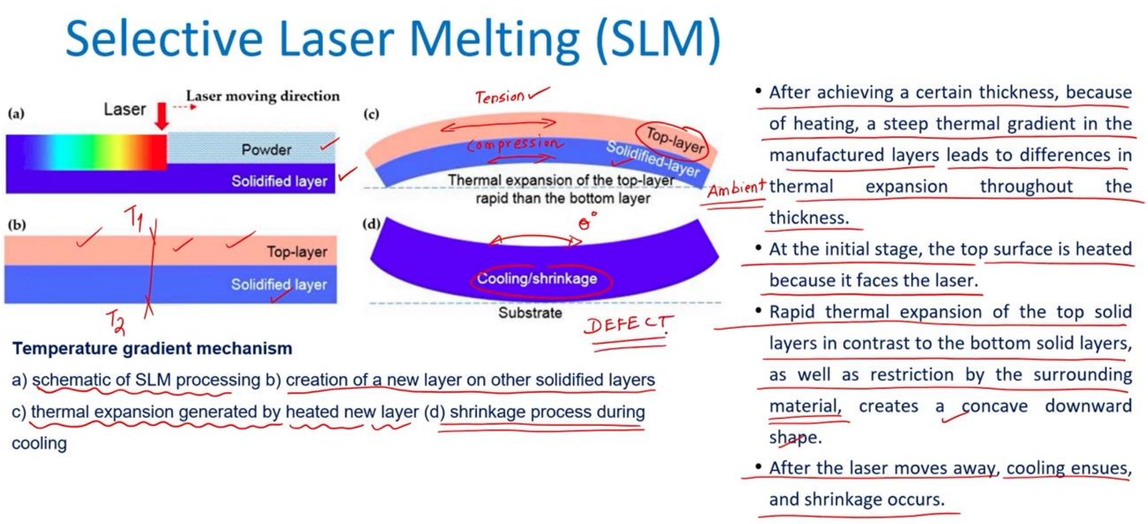

However, there is a little limitation of the SLM, when we want to develop the thin products or thin cross sections, there may be chances of distortion of deformation, uncontrollable deformation of the work parts, and it is primarily due to the TGM, that is a temperature gradient mechanism which we have seen in our laser based forming operation.

What is this TGM and how it is occurring in the SLM as well? That we will see right now. On your screen you can see there is a solidified layer, this is the solidified layer and we have laid down a layer of powder over the solidified layer. Now, during the process of application of laser there is melting, melting of this layer is occurring, there is a melting and solidification. There is a melting and solidification. Top layer has been fabricated but the temperature of the top layer is comparatively very high with respect to the solidified layer. As the top layer is hot, its temperature is very high, it will expand - its fibers or molecules will expand, and this expansion is also applied over the solidified layer, but the solidified layer is at ambient temperature, so it is cooler, and there are generation of compressive stresses in solidified layer. However, surface of the top layer is in tension. There are tensile stresses which are occurring at the top layer. However, this layer - the bottom layer is in compression, which is very similar to the laser forming operation that we have seen in the TGM.

Like the laser forming in TGM, as the laser is passing over the work part the temperature will get reduced and during the cooling operation there is the deformation of the work part. In a similar way during solidification there is deformation of the work part towards the laser beam, that is nothing but a problem which is occurring during the laser based selective laser melting as well. Very similar to the laser based forming, as there is the bending occurring towards the laser beam, in a similar way here as well there is a permanent deformation is occurring towards the laser beam in a very small way, but it is the limitation, it is the drawback or the defect of the SLM or SLM based products.

The first schematic is of the SLM processing. There is creation of new layer on the solidified layer. During the process of heating there is a thermal expansion of the new layer and during the cooling operation there is a shrinkage process during the laser getting pass over the work part. This shrinkage or cooling is leading to the deformation. This is the deformation, it is in a very small degrees of angle. However, when we talk about using of the SLM products for the precision applications, this minor defect will also not be tolerated. After achieving a certain thickness because of hitting a steep temperature gradient in the manufactured products and that is leading to the differences in thermal expansion throughout the thickness. As I mentioned, there is a thermal gradient between the temperature at top surface and the temperature at the bottom surface. At the initial stage the top surface is heated because it is facing the laser. There is a rapid thermal expansion of the top solid layers in contrast to the bottom solid layers, as well as there is a restriction by the surrounding material which is very similar to laser forming and it is creating a concave downward shape during this operation. After the laser moves away, cooling ensues and shrinkage occurs. This is the creation of defect and to avoid this we have to select the process parameters in a very proper way.

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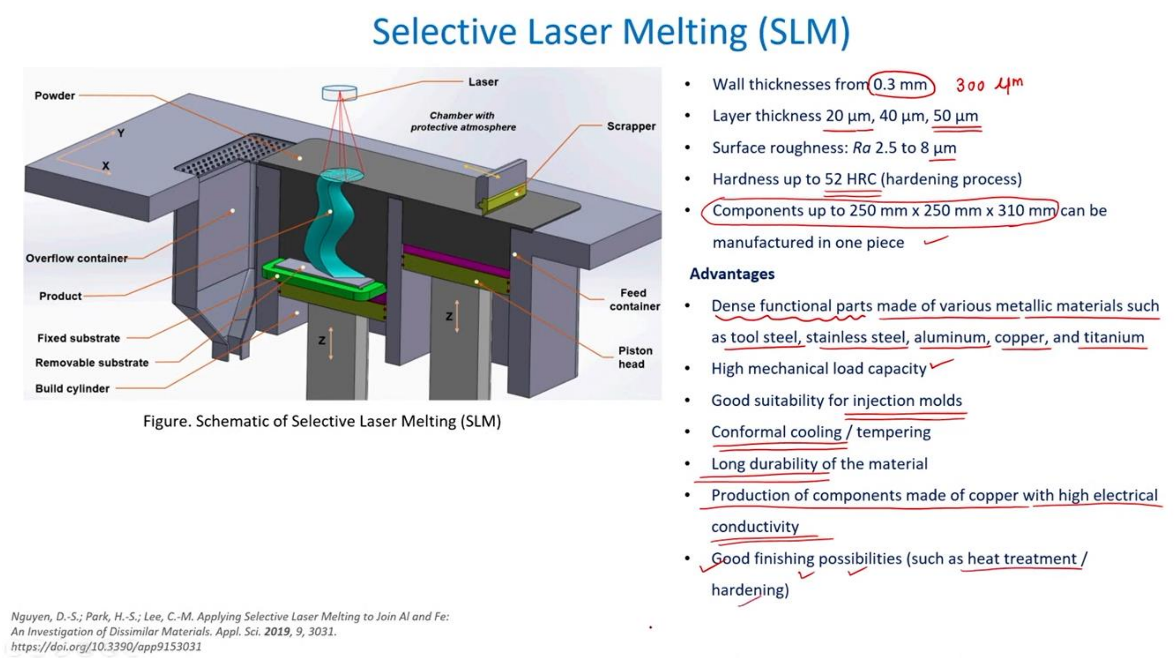

Now let us see some of the technical specifications of SLM. During the SLM process, we can achieve a wall thickness of about 0.3 mm that is about 300 micrometers. We can have the laser thickness in the range in the range of 20 microns to 50 microns. During this operation of SLM, we can achieve the roughness in between 2.5 to 8 microns. And then we can increase the hardness of this SLM based products up to 52 HRC. The component sizes which we can achieve is up to 250 mm by 250 mm by 310 mm in general. If you just notice, the very small parts can be manufactured by using this SL. Bigger parts consume a huge amount of energy, which is sometimes it is not feasible, not economical.

What are the advantages of the SLM process? We can manufacture dense functional parts which are made-up of various metallic materials such as tool steels, stainless steel, aluminum, copper and titanium. The parts which are made-up by SLM are having high mechanical load carrying capacity, they are finding very good applications in injection molding, we can have the conformal cooling during the operation, we can even manufacture the holes - cooling holes during the manufacturing of these dyes and molds, which are very difficult or sometimes not possible by using conventional or unconventional material removal processes such as EDM process or other material removal processes it is not possible to generate the conformal cooling channels, the cooling channels inside the molds and dies through which we can pass the chilling water or the fluid to take away the heat.

The SLM parts are giving us long durability and the production of components made of copper with high electrical conductivity. We can easily manufacture components or parts of copper with high electrical conductivity. These parts are showing good response or they are cooperating for the finishing operations as well, such as heat treatment and hardening operations.

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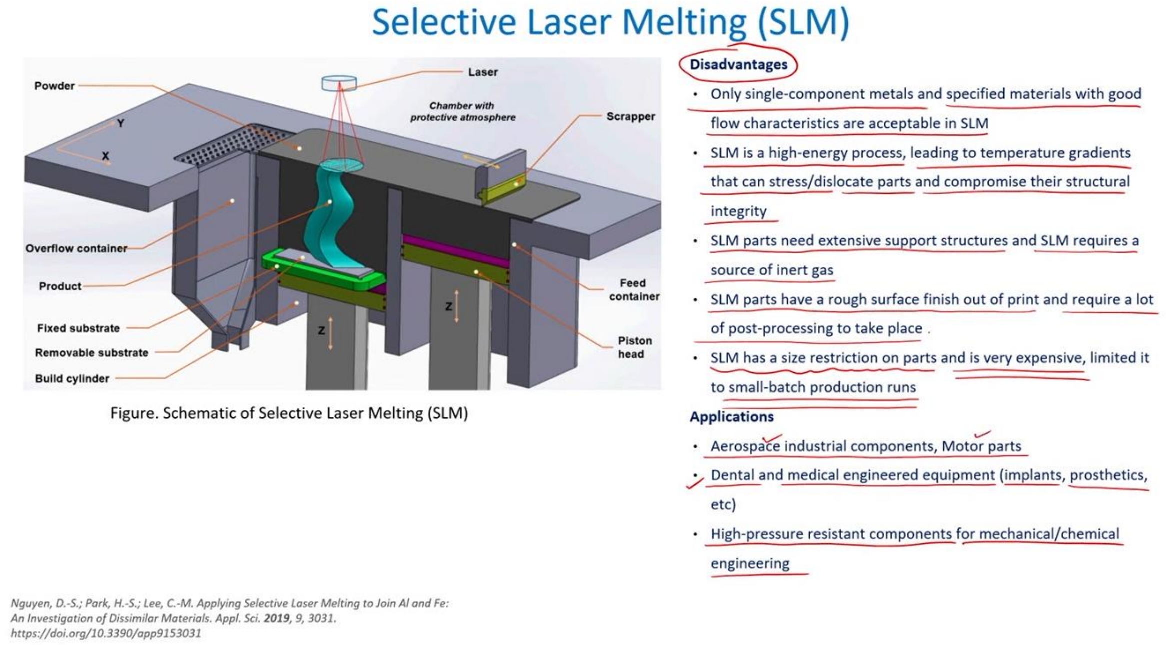

However, there are certain disadvantages of SLM. Only single component metals or specified materials with good flow characteristics are acceptable in SLM. In SLM we can use a single material to manufacture the part, but sometimes we may need to have the multi or dissimilar parts to be layered or dissimilar parts to be used. That is difficult, but a lot of research is being carried out in the industry and in academia to deposit two different materials, dissimilar materials by using this SLM process.

SLM is high energy process, leading to temperature gradients that can stress or dislocate parts and compromise their structural integrity. To melt the powder, we have to apply high flux density and during the process of application of high flux density there is a generation of stresses and dislocation of parts. Moreover, the structural integrity, the mechanical properties of material will get harmed due to the high temperature that we are applying and high energy that we are applying.

SLM parts need extensive support structures. SLM requires a source of inert gas as well. When we are manufacturing complex parts with overhanging structures, we need the extensive support structure to carry out this and to design, develop and to manufacture these support structures we have to consume some energy, we have to consume some material. This is adding a burden to the manufacturing of SLM based products.

Moreover, there is a requirement of the inert gas or a vacuum or controlled environment to carry out this operation. SLM parts have a rough surface finish out of print and require a lot of post processing to take place. Of course, we are melting the material and then we are allowing it to solidify and during the solidification, fusing is getting occurred. There is little control over the surface finish that we are getting. Moreover, there may be chances of having oxidation as well, lot of post processing is needed on the SLM part.

SLM has size restriction on the parts and it is very expensive. As I mentioned, very small size parts can be manufactured by using SLM. If you want to manufacture huge parts which are having sizes in meters, it is not possible, it requires lot of energy - specific energy consumption would be enormous in this case. Even to manufacture such as small components, the energy consumption is very high, therefore, these deposited parts or SLM based products are very expensive and they are limited to a small batch run production as well. Small batches manufacturing process can be used and not for the mass production or the continuous production.

What are the applications of SLM? SLM can be used in aerospace or industrial components manufacturing, motor parts. These are also used in dental or medical engineering equipment implants, prosthetics. The SLM is also very much useful in high pressure resistant components for mechanical and chemical engineering. It has a lot of applications not only in the dental or you can say biomedical engineering for aerospace and the automotive as well the SLM is finding lot of applications.

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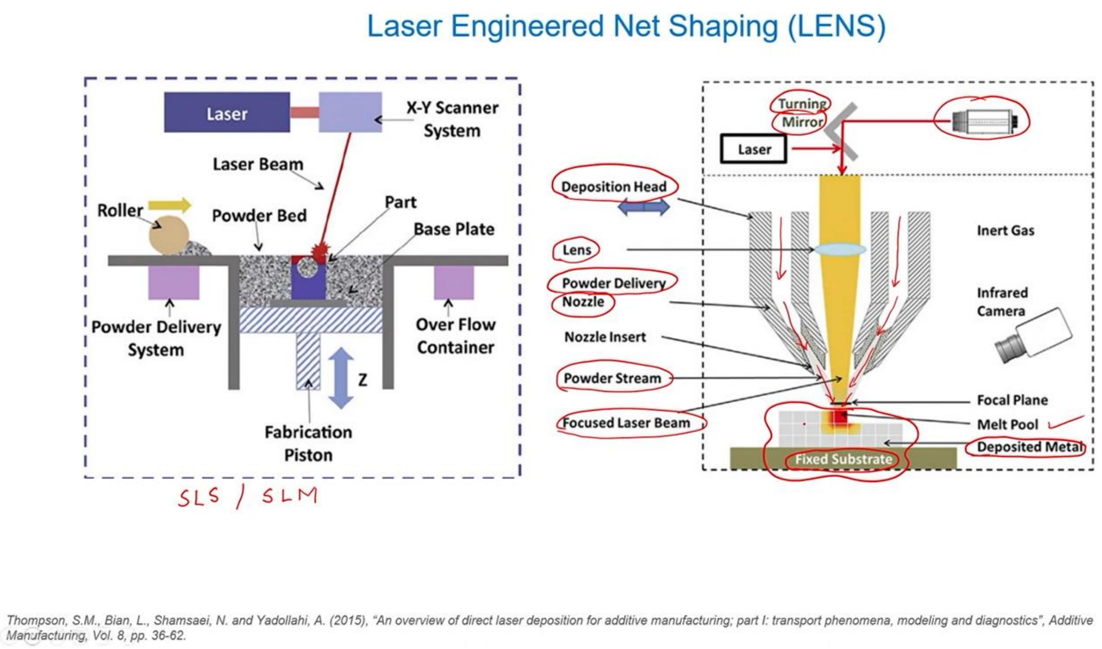

Till now we have seen the two processes, that is SLS process (Selective laser sintering) and SLM process that is, a selective laser melting. That schematic is already discussed and again it is there on the screen. But in certain industrial applications, we want to manufacture very complex shapes and to manufacture the complex shapes we are compromising with the basic shape that we are getting during the 3D printing and its surface finish. We are trying to go near to the final shape that we are getting during 3D printing and afterwards we will go for its extensive post processing, we have to do lot of machining, washing or we have to carry out the post processing in terms of the grinding applications as well.

Let us get the near net shape product by using laser based deposition and that particular process is called as laser engineered net shaping. Here in this case we are trying to build, we are we are trying to build up a 3D product by using a laser based deposition which will take us near to the product and then we apply the post processing application.

Laser engineered net shaping is an extension of the laser cladding process. Laser engineered net shaping, which is popularly being called LENS is just an extension to the laser cladding process. Its schematic is there on your screen. Here we want to develop the work part, this is the work part that to be developed which you can see over here. This is the fixed substrate and over which we have to deposit the metal. Needless to say that the LENS is there for the metallic objects only. And here now we are using a laser, this is a laser beam energy source, there is a turning mirror and the laser is being applied. During the application of laser, we are using powder of the metal that is being applied simultaneously with application of laser beam energy. It is not the powder bed that we are creating over here. As the laser beam is getting applied, around that laser beam itself we are allowing the powder to get applied over the surface and during the process of application of powder over the surface, the powder is getting melted and it is getting fused with the substrate material, it is getting fused with other particles of the powder which is coming next to it.

During this process we are getting a layer and there is a maneuvering, there is a movement of the laser beam head or the entire equipment which is having the nozzle as well as the laser beam with respect to the work part. Here we are having the deposition head, or it is also called as the nozzle. It has the lens through which the laser beam energy is focused. The deposition head is having powder delivery nozzle. This is the powder delivery nozzle and through which we are applying the powder at the site. Here this is the concentric nozzle through which we are applying the powder.

We are getting the powder stream at the site of application and this is the focused laser beam. When the laser is getting interacted with the powder, it is melting the powder, it is melting the surface as well, then the fusion will occur.

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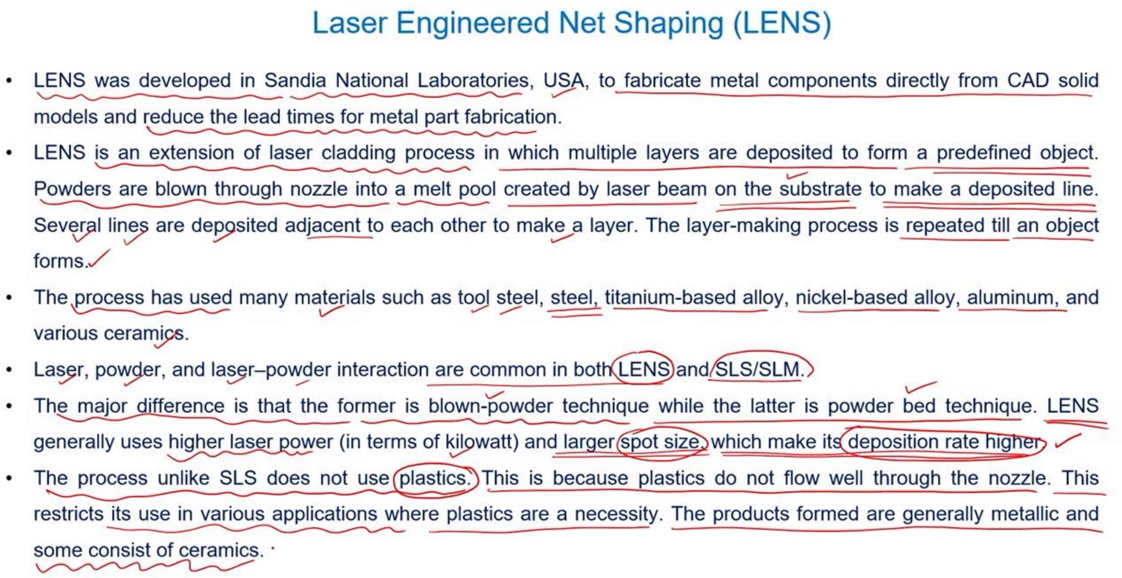

The process of LENS was developed in Sandia National Laboratories, USA, to fabricate metal components directly from CAD solid model. As I mentioned, to manufacture or to develop metal solid models, the LENS was developed and the main application of the laser engineered net shaping was to reduce the lead time in metal part fabrication. To reduce the lead time or the development time of metal part fabrication, this LENS based technology was invented. It is an extension of laser cladding process in which multiple layers are deposited to form a pre-defined object. Powders are blown through nozzle into a melt pool created by laser beam on the substrate. Here we are blowing the powder through the nozzle into the melt pool which is created by the laser beam. And this laser beam is being applied on the substrate. Then we can move the application of laser beam along certain line, along certain direction as per given by the CNC machine tool. Several lines are deposited adjacent to each other to make the layer. The layer making process is repeated till an object form. We are repeating this process of application of layers continuously to get the required object done.

The process has used many materials such as tool steels, steel material, titanium-based alloys, nickel based alloys, aluminium and various ceramics. It is interesting to note that the laser powder and laser powder interaction are common in both LENS, SLS and SLM. Laser material interaction, the type of laser which we are using, the type of powders that we are using all are same, but the methodology is different in the LENS as well as in SLM process.

The major difference is that, the former is blown powder technique, while the latter is powder bed technique. LENS here it is a blown powder technique and SLM are the powder bed technique. In LENS, we are in general using very high laser powers, in terms of kilowatts and very larger spot sizes which are making its deposition rate very high. During this process of operation, very high laser powers are being used and the spot sizes are also very high, which are making the deposition rate very high. The high-power rate and very larger spot sizes are making the deposition very high, very fast during this lens operation.

The process, unlike SLS, does not use plastic. Here in LENS, we are not fabricating the parts which are made-up of plastic. This is because the plastics do not flow well through the nozzle. The fundamental problem of the plastic is that through the nozzles they are not properly being blown over the surface due to that the plastics are not used in the LENS based process. This restricts its use in various applications where plastics are necessity. The products formed are generally metallic and some of the products are consisting of the ceramics as well.

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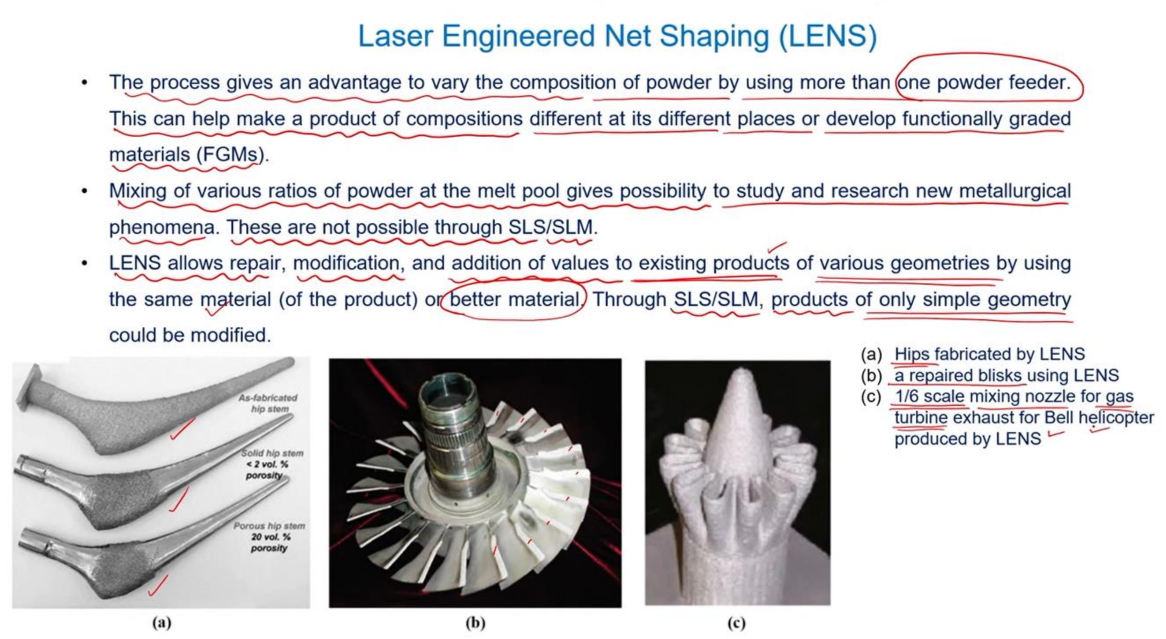

The process gives an advantage to vary the composition of product. As I mentioned in SLM, the problem is carrying out the deposition of two different materials, dissimilar materials, and that has been solved by using this laser engineered net shaping. Here this process is giving an advantage to vary the composition of powder by using more than one powder feeder, and we can change the composition, we can change the percentage of the elements during this process of LENS. These can help to make a product or compositions of different powders at different places and to develop functionally graded materials. During the production, we may need to have more dense part at one side or one portion, the density has to be more at other portion the density has to be less. When we want to vary the density of the elements or the composition of the product, these kinds of products are called as functionally graded materials. We are changing the composition, we are changing the density, we are changing the material properties at various portions of the same part or the same product and that different portions or different parts are being used for different functions. As per the functions we have to change the grade of the material, and so these are called as the functionally graded materials and by using LENS based process we can easily manufacture such FGMs that is a functionally graded materials.

Mixing of various ratios of powder at the melt pool gives possibility to study and research new metallurgical phenomena. By having various compositions, by combining various elements or various metal powders together, we can easily manufacture variety of products and then we can test them, we can test the capability, we can test the feasibility of combining various metal powders with various metals together and we can create variety of alloys and then test them in the physical condition. Therefore, for research applications, this LENS is providing a lot of opportunities to the academia and as well as the industrial researchers. This capacity is not there with SLS or SLM, and so there is no possibility to mix up two different materials and to test the compositions for variety of the grades.

LENS are allowing for repair, modification and addition of values to existing products. It's not only to manufacture the parts from its origin, from its basic substrate. Already developed parts, already used parts can be repaired, they can be refurbished by using LENS based applications and this saves lot of energy that already we have put in to develop certain parts. May be due to some problems, some fractures or some distortion at the surface we need to dispose it off, so that can easily be solved by using LENS process and it saves lot of energy, lot of economy. These existing products can further be refurbished, we can even change their geometries as well, either by applying the same material or by applying the better material. We can coat these worn-out materials, worn out products by giving the coating of the refractory materials or the materials which are providing the better wear characteristic or wear properties. In SLM there is no such possibility, because we can only process simple geometries, but in LENS as we are depositing like the cladding process that we have seen, any complex geometrical products can be easily repaired or maintained.

On your screen you can see a variety of products which are LENS processed. The first is the hips, these are the hips which are being processed by using the LENS. The second one is the repaired blisks. These are the blisks of a component - a mechanical component and these are repaired by using the LENS process and the third one is 1/6th scale mixing nozzle for the gas turbine. It is a small nozzle or 1/6th scale nozzle which is developed by LENS process and this is of the Bell helicopter.