Laser Based Manufacturing
Prof. Shrikrishna N. Joshi
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Module No # 05
Lecture No # 17
Laser Cladding

Hello friends, I welcome you all to the last lecture of Week 5. This is lecture number four of NPTEL Online MOOCs course on laser-based manufacturing. In this week, we are studying various laser surface treatment processes and till now we have seen two major processes. First is laser surface hardening and second is laser surface alloying. So, in this lecture we will be studying laser cladding.

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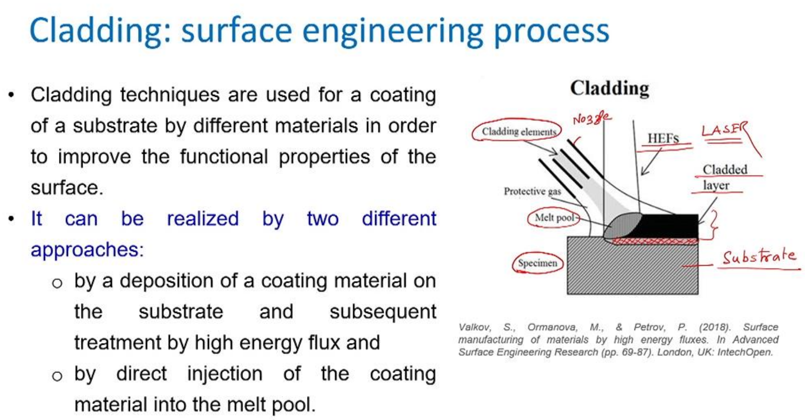

Cladding is another surface engineering process. And in cladding techniques, we are applying the deposition material but the thickness of that cladded material would be significantly high in comparison with surface alloying process. This cladding technique is used for coating of a substrate by different materials and the objective is very similar to our previous processes, that is, to improve the surface properties. Now this cladding can be realized by two different approaches. The first approach is by deposition of coating material on the substrate material and subsequent treatment by high energy flux. In the first method you have to deposit the material and then you apply the laser energy. Then you apply the heat flux over the surface and that heat flux intensity must be very high. In the next cladding way is the direct injection. In this case we are injecting the coating material into the melt pool. So, by using high energy fluxes we are creating the melt pool and then the material that to be cladded will be injected over the surface. It will get resolidified and then there is a fusion of deposited material with the substrate material. But the fusion is occurring at the interface only, and the cladding material will not be losing its material properties significantly. As there is no complete mixture of the cladded material with the substrate is occurring, there is no complete dilution of the cladded material with the substrate is occurring, the cladding surface will have the material properties of the deposited material. Now let us look at the schematic of the cladding process. On your screen you can see the specimen, substrate over which you have to clad the material. We are using cladding elements which are passing through nozzle. So, this is nozzle. We required high energy fluxes and, in this case, it is laser. Now when we apply the laser beam energy then there is melt pool which is getting generated. And after the melt pool generation and when the laser will passover then cladding will occur, there would be solidification of the melted pool will occur. This solidification you can see over here, which is of the cladded material deposited material. At the interface, there would be a change in material properties there would be a mixture of the cladded material with the substrate material that is at the interface. This is the difference between the laser surface cladding and laser surface alloying. In alloying, the entire molten material will be a different combination than the substrate material and deposition material. However, in the cladding at the surface, at the interface of the. Substrate and the deposition material there would be a mixture that is occurring. So here, we want to have the material properties of the cladded material over the surface and substrate material will also have its own material properties.

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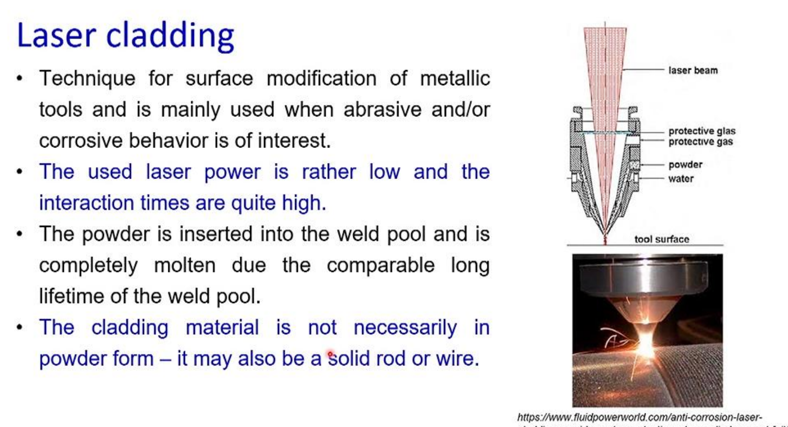

On your screen you can see a typical laser cladding, which is getting done. Here you can notice this is the thickness that we are getting during the laser cladding operation. This is substrate and this is laser cladded surface. So, you just notice a significant thickness we can achieve by using laser cladding process. This is a typical nozzle of the laser cladding equipment. This nozzle is having an opening through which laser beam is getting applied over the surface. It has a protective glass. And there is opening in the nozzle through which we are applying the protective gas as well: inert gas. There is an opening for powder that is to be applied at the tool surface and we also required water. Water here is being used to chill or to apply the convective heat transfer to take away the extra heat which is getting generated during this operation. To safeguard the nozzle from excessive heat. Chilled water is being used. Laser cladding is a technique for surface modification of metallic tools and is mainly used when abrasive or the corrosive behavior is of interest. To improve the abrasive wear properties, to improve the corrosive behavior of the work parts, we are going for the laser cladding. Laser power here is low, so here you notice that we are not applying high energy power, we are not applying higher levels of laser power. The power is low. And the interaction time is quite high. Here we are maintaining the energy that we are putting in in terms of more interaction time. Although the power is less. The powder is inserted into the melt pool and is completely molten due to comparable long lifetime of melt pool. As we are enhancing the interaction time, there would be long lifetime of the weld pool and during this process of solidification, we are injecting the cladding material. We are applying laser power. Laser power is melting the material for longer duration of time and during that period only we are applying the cladding material. The cladding material is not necessarily in the powder form or we can have the cladding material in terms of solid or we can have in terms of wire as well.

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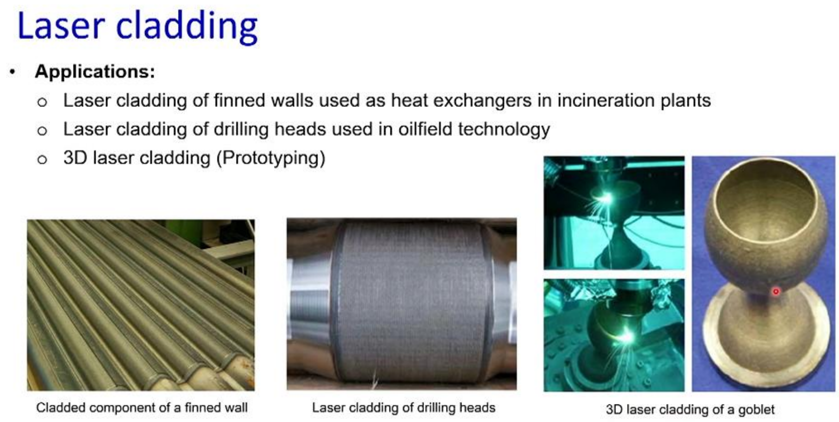

There are many applications of laser cladding. On your screen a variety of pictures there. This is the cladded component of a finned Wall. And here these are the drilling heads. The surface is laser cladded. And even we can carry out the 3D laser cladding of a goblet. This is the laser cladded surface.

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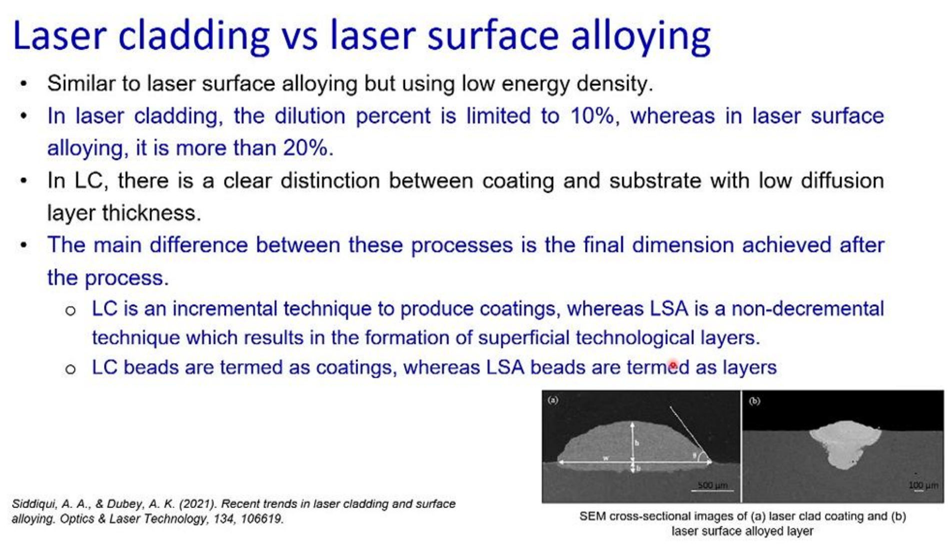

Fine! Let us understand the meaning or the difference between laser cladding and laser surface alloying. Similar to laser surface alloying the cladding is used to deposit the materials over the substrate material. But the energy density is low. In cladding, the energy density is low. In laser cladding, the dilution percent is limited to 10 percentage, whereas in surface alloying it is more than 20 percentage. This is a very important difference between laser cladding and laser surface alloying. In laser cladding there is a clear distinction between coating and substrate with low diffusion layer thickness. Here you can see there are two images. And the first image is the laser clad coating. This is the laser cladded coating and the second one is the laser surface alloyed layer. From the substrate surface, you can just notice that the laser surface alloyed is deep inside and these material properties of the newly formed material is different than the substrate material and deposited material. Here you notice this is the interface zone and inside the interface zone only there is a change in material properties. The substrate material properties are unchanged and there may be slight changes in the solidified material properties of the cladded materials. The main difference between these processes is the final dimension achieved after the process. In cladding, the cladding is an incremental technique to produce coatings, whereas LSA is non-incremental technique, which results in formation of superficial technological layer. In LC, in cladding we are applying layers and further these layers can be built up to create a 3D structure as well. Cladding is an incremental technique. You can apply more layers to enhance the thickness of the cladded layer, but in LSA it is non-incremental. Here we just want to change the surface properties. The cladding beads are termed as coatings, whereas the alloyed beads are termed as layers. In laser surface alloying we are calling the beads as layers. In the cladding, we are calling the beads as coatings.

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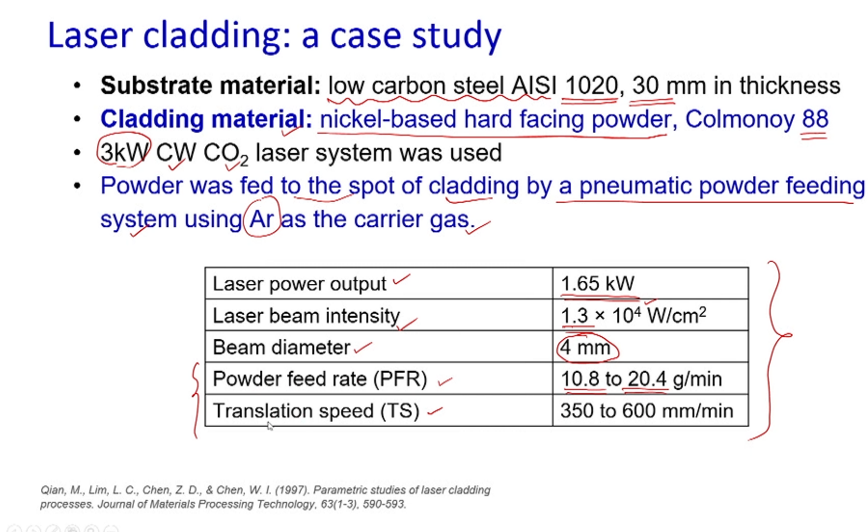

Now let us have a case study on laser cladding. Here, we are taking a low carbon steel AISI 1020. Its thickness is 30 mm and we are cladding a nickel based, hard facing powder over it. To have the cladding of nickel based, hard facing powder and Colmonoy 88 material, we are using a three-kilowatt continuous wave CO_2 laser. The powder we are feeding to the spot of laser cladding by a pneumatic powder feeding system and argon is used as the carrier gas as the inert gas as well. These are the process parameters on your screen were applied. The laser power was about 1.65-kilowatt, beam intensity was about 1.3 into 10, raised to power 4 watts per centimeter square, beam diameter was about 4 mm. PFR, that is the powder feed rate, was about 10.8 to 20.4 gram per minute. These are the two important parameters here. That is a PFR, powder feed rate and translation speed, the speed of movement of the substrate and that is about 350 to 600 mm per minute. Scan speed and powder feed rate, these two are the important parameters to be considered during this case study.

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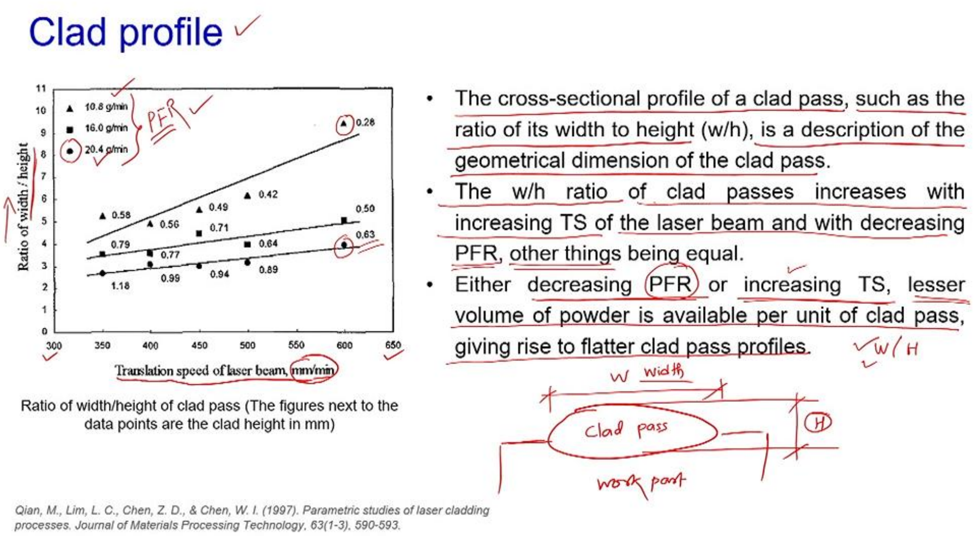

Now let us study the effect of TS that is our translation speed. This is the translation speed of laser beam which we have taken in mm per minute on x-axis and that is varying from about 300 mm per minute to 650 mm per minute. And on y-axis we have taken the clad profile. Clad profile here is defined in terms of width to height ratio. The width of the bead to its height. That is the clad profile that we are defining here. The cross-sectional profile of a clad pass such as the ratio of its width to height is the description of the geometrical dimension of the clad pass. Geometrically, we are considering this is the cladded surface or collided bead over the work part, its width to its height are considered here. Width and height. This is the clad pass. And this is work part or substrate. Now what we are noticing here for different PFR. These are the PFR value, powder feed rate values. For variety of powder feed rate values, it has been noticed that, as the TS is increasing, the profile is getting improved. The ratio of width to height ratio is getting improved. You just see here as we are increasing the translation speed, the ratio of width to height is increasing, but there is an interesting observation also can be noticed that the clad profile is more in case of low PFR values. So, if you just look at the field in triangle which is with respect to low PFR and field in circle which is with respect to high PFR. Here you notice that this graph is giving low values of clad profile, higher PFR is giving us low clad profile and low PFR is giving us high clad profile. The W by H ratio, width to height ratio of clad passes increases with increasing TS. Right! While it is decreasing with PFR when the other things other process parameters are equal or constant. To have the higher width to height ratio, you can decrease the PFR value or you can increase the TS value. So why this is happening? The reason is that the lesser volume of powder is available per unit clad pass giving rise to a flatter clad pass profile. When we are having decreasing PFR value, when low amount of powder we are applying then we are getting flatter clad pass profiles. This W by H ratio is dependent upon higher values of width. When low values of PFR are there, when low volume of powder is available, then certainly we are getting a flatter clad profile. And it is also related to increasing the translation speed so low interaction time is also maintained. That's why we are getting flatter beads as well.

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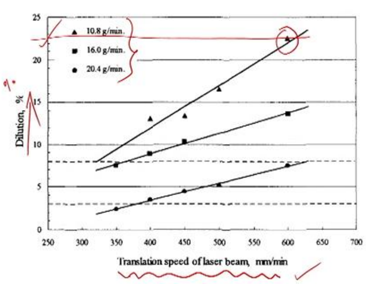
Dilution



The dilution of clad pass

- Dilution of the cladding metal, defined as the proportion of the parent metal (substrate) in the clad layer
- The dilution of the clad layer increases with increasing TS and decreasing PFR.
- Higher TS for a given PFR or lower PFR for the same TS gives a higher degree of dilution.
- This is the result of lesser volume of powder available per unit length of clad pass when either PFR is decreased or TS is increased.

Qian, M., Lim, L. C., Chen, Z. D., & Chen, W. I. (1997). Parametric studies of laser cladding processes. Journal of Materials Processing Technology, 63(1-3), 590-593.

Now there is another parameter that we will, also take into consideration. That is the dilution. So, dilution in case of laser cladding is defined as the proportion of the parent material or the substrate in the clad layer. We have to find out how much is the dilution of the parent material inside the clad material. In laser cladding, this is considered is not desired. There should not be more amount of dilution of the substrate material inside the clad material. At the interface only there has to be the dilution of the substrate material inside the clad material. The dilution of the clad layer increases with increasing TS and decreasing PFR. Here we have taken translation speed on x-axis and the dilution on the y-axis. It is in percentage. Again, we varied the PFR in three levels: 10.8 gram per minute, 16 gram per minute and 20.4 gram per minute. Now, you can notice here the dilution percentage is increasing with TS, that is the scan speed. But it is decreasing with increase in the PFR. If we are putting up more powder feed rate, then the dilution is getting decreased. Higher TS for a given PFR or lower PFR for the same TS gives high degree of dilution. If you are working at very high TS value, high translation speed value, and if you are working with lower PFR, here you can see this is this is the lower PFR value than you are having higher degree of dilution. The dilution is much higher in this case. This is the result of lesser volume of powder available per unit length of the clad pass when either PFR is decreased or the TS is increased. So, this higher degree of dilution is again related to the volume that you are applying for the cladding material. When there is lower value that you are applying for the deposition, then there would be more dilution getting occurred during the deposition. So, that is the conclusion of this particular graph.

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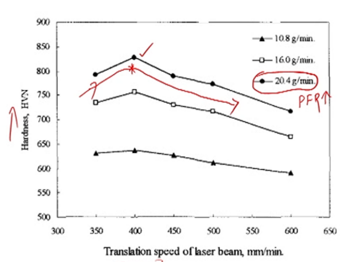
Surface hardness



Surface hardness of clad layers

- Clad passes produced at higher PFRs generally registered a higher hardness than those clad at lower PFRs.
- More interestingly, at a PFR, there exists a peak hardness which occurs over a ranges of TS of the laser beam.
- For the cladding parameters considered, the highest hardness was obtained at the PFR of 20.4 g/min over a rang of TS from 350 to 450 mm/min, while other PFRs produced consistently poorer hardness values.

Qian, M., Lim, L. C., Chen, Z. D., & Chen, W. I. (1997). Parametric studies of laser cladding processes. Journal of Materials Processing Technology, 63(1-3), 590-593.

In addition to the dilution and the clad profile, we can also study the surface hardness. The clad passes produced at higher PFRs generally register higher hardness than those clad at lower PFRs. For higher PFRs, so if you notice higher PFRs are these: 20.4 gram per minute when we plot TS along x-axis and hardness along y-axis. For higher PFR values the hardness are more. Interestingly, at a PFR there exists a peak in the hardness which occurs over a range of the TS of the laser beam. If you just notice over here there is a peak is occurring in the hardness and then it is getting reduced. The hardness is getting increased, it achieves its peak, it attains its peak and then comes down. This is achieved at a range of about 3:50 to 4:50 millimeter per minute for the TS, for the translation speed and for the higher value of PFR that is about 20.4. So, for 20.4 and in between 350 to 400, a maximum hardness was achieved.

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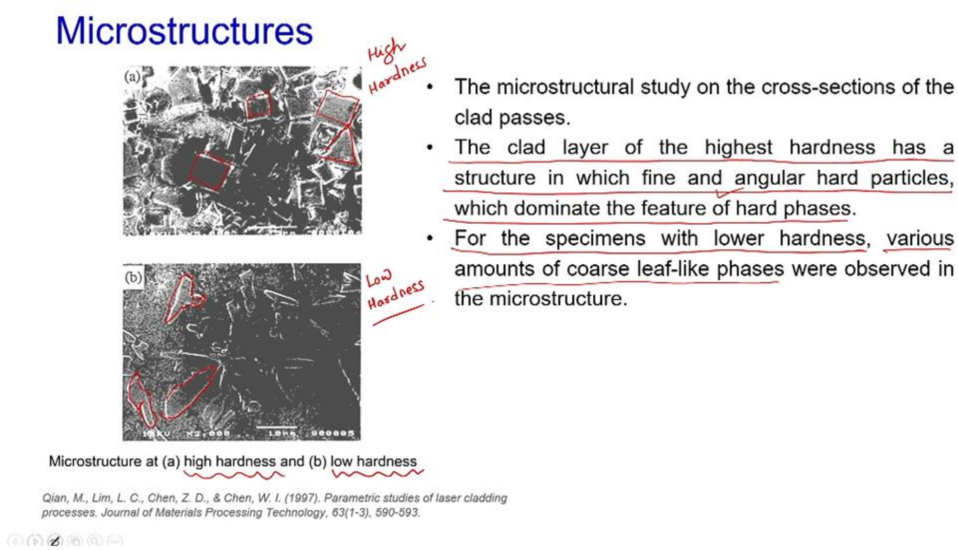

Now let us look at the microstructures which are generated during this laser cladding process. On your screen you can see the microstructure at high hardness and low hardness. So, this a belongs to high hardness. This is the micro structure related to high hardness. And this is related to low hardness. What we noticed here the clad layer of the highest hardness has a structure in which fine and angular hard particles, and these are dominating the feature of hard phases. So, if you just look at this microstructure, you will find that there are angular hard particles. These are all the angular hard particles that you can notice. They are fine. But they are angular and these are the hard particles which are increasing the hardness. For the specimens with lower hardness, various amounts of coarse leaf like phases were observed. These are the Leaf-like phases which were noticed during the optical micrograph study for the lower hardness cladded material.

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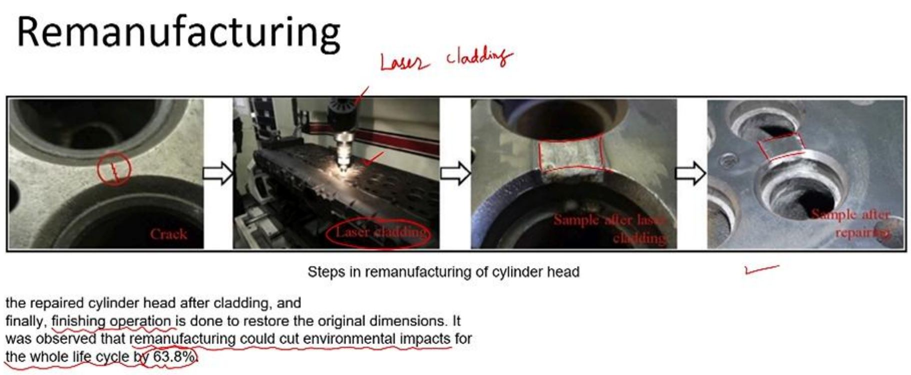

Now let us see what are the various applications of laser cladding. Here you can see there is a cylinder head and there is a crack which has occurred at the cylinder head. And by applying the laser by carrying out the laser cladding operation, this is the laser cladding which is getting done, so this surface is cladded over here. And after that it was finished this surface was finished and is ready to use for further applications. The repaired cylinder head after the cladding that you can notice over here. Finishing operation is, of course, essential to make it ready for final application and to get its original dimensions. It was observed that the remanufacturing could cut environmental impacts for the whole life cycle by 63.8 percentage, approximately 60 percentage of the environmental impact for going for a new product can be saved. So, this simple laser cladding is saving the entire cylinder head and which have saved a lot of energy, lot of resources and money as well.

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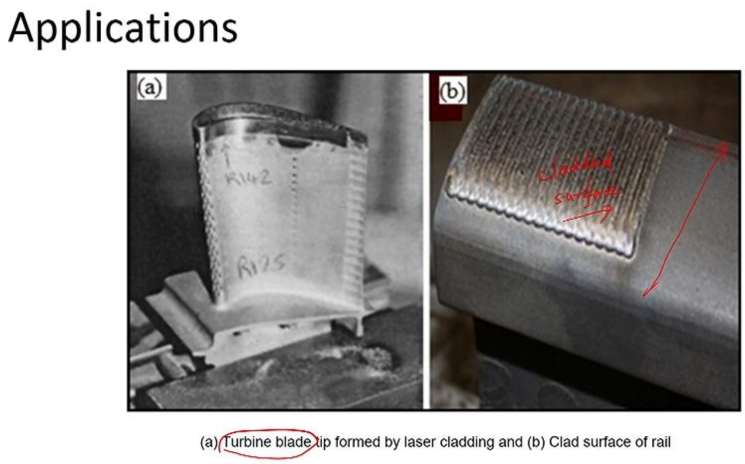

Two more examples are there in front of you. Here we are having a turbine blade tip. This is a turbine blade tip which is laser cladded. And this is a rail surface. And this rail surface has been cladded, this is a cladded surface.

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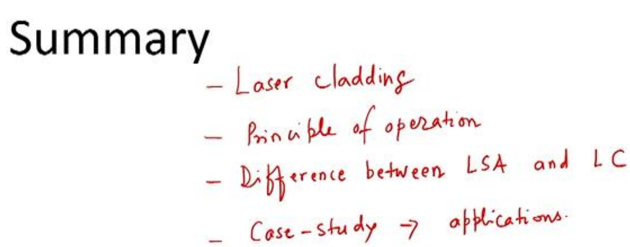

Fine! So, with this I would like to summarize today's class. We have seen laser cladding, its principle of operation, the difference between LSA, that is laser surface alloying and LC, that is a laser cladding. And at last, we have seen a case study with certain applications. With this I would like to conclude this lecture the lecture 4 of Week 5. In addition to this, I also conclude this week as well on laser-based surface treatment. In the next week, we will study the additive manufacturing techniques where lasers are used. Till then goodbye! Thank you!