Laser Based Manufacturing
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Lecture – 15
Laser Surface Hardening

Hello friends. I welcome you all to the second lecture of Week 5. In this week, we are studying an interesting application of lasers that is in surface treatment. In our previous class, we have seen various heat treatment techniques and then we have seen how lasers can be used to improve the surface properties. Let us begin and see how the lasers can be used for surface hardening.

The fundamentals of using lasers for two different applications that is the hardening and cladding that we have seen in our previous class.

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In this lecture, we will be studying or we will have a case study and through that case study we will study how the lasers can be used to harden the surface.

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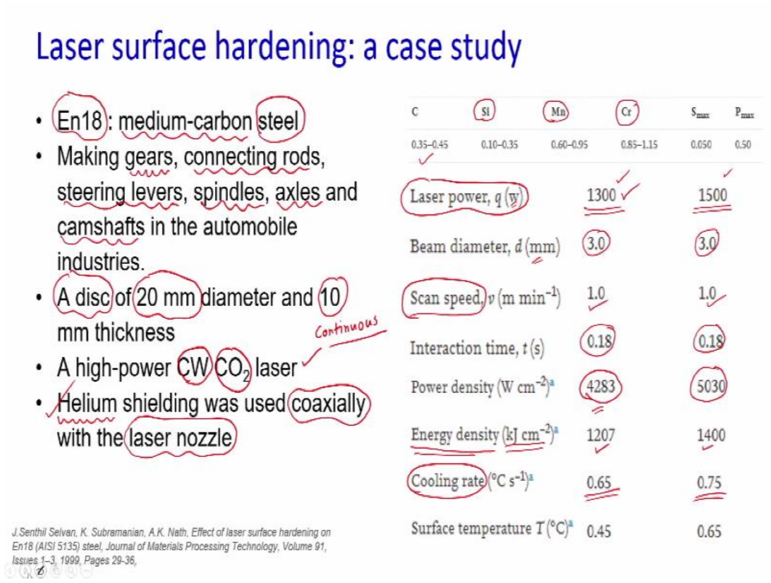

Now, to understand the process of laser surface hardening let us take a material and that material is En 8 it is medium carbon steel. It is a steel material with a medium percentage of carbon. The composition of the material is there in front of you. The carbon percentage is approximately 0.35 to 0.45 percentage. It has silica, it has manganese, chromium and other factors.

This is very useful industrial material and it is used to manufacture gears, connecting rods, steering levers, spindles, axles and camshafts. So, all these parts are required to build up a mechanical system, a manufacturing system in which précised components are needed to have the desired motion of the linkages, desired moments of the linkages, desired application of forces in the mechanism.

For the experimental study we are considering a disc and the diameter of the disc is about 20 mm and the thickness of the disc is 10 mm. A small circular disc we are taking with this dimension and then we will be carrying out the hardening operation. To carry out the hardening operation we can use high power lasers either it can be generated by using solid state laser such as Nd:YAG laser or we can use CO2 laser.

Here the CO2 laser is taken. It is in CW mode; it is in continuous mode, it is not in pulse mode. It is a continuous laser we will be using for the surface hardening process. As we have seen in our previous class as well we need to have a shielding gas and inert gas during our operations. So, helium is considered. Here it is having a coaxial nozzle and through this coaxial nozzle the helium gas is applied to protect the surface from the oxidation. There is a nozzle which is required here and through the nozzle the helium is coming down it is getting applied on the surface.

For this experimental study a set of process parameters have been chosen and these parameters are there on your screen. We have taken the first important parameter that is laser power it is in watt and two steps, two stages or two levels are taken that is 1,300 watt and 1,500 watt. The beam diameter, the laser spot diameter is in millimeters that is about 3 mm for both the cases. The scan speed it is in meters per minute or we can convert it into mm as well.

It is a 1,000 mm per minute that is also constant we are not changing the scan speed. The interaction time is 0.18 seconds it is very small. The density is getting changed as the power is getting changed. For 1,300 watt the density is less naturally it is 4,283 watt per centimeter square, for 1,500 watt it has increased, enhanced to 5,030 watt per centimeter square.

The density of the energy in kilo joule per centimeter square is there on your screen. The cooling rate has been computed that is about 0.65 to 0.75 degree centigrade per second.

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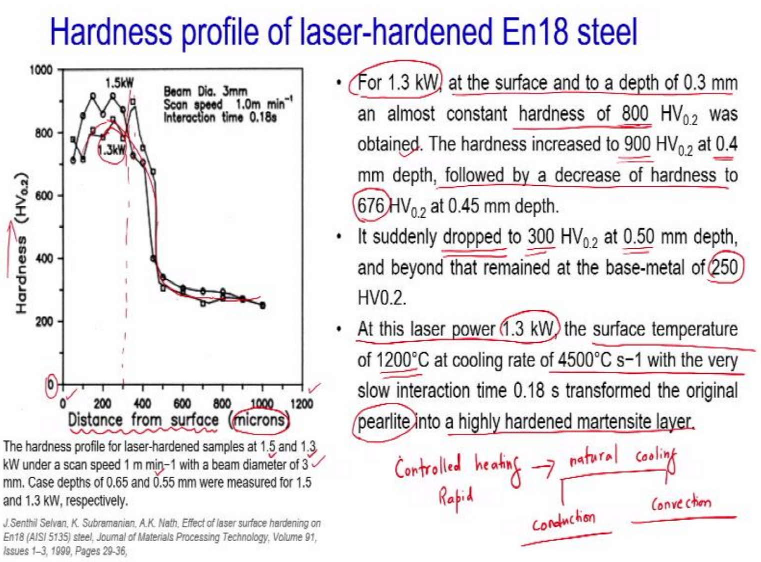

Fine, now, let us see what are the various results were obtained during this laser surface hardening. As we have seen in our previous class in laser surface hardening we are carrying out controlled heating of the work part. Controlled heating and that is also rapid and then natural cooling due to surrounding medium. Cooling would be done by conduction mode as well as the convection mode.

In conduction mode, it would be prominent because a bulk of material would be available for the conduction. We are applying laser for very small area for a very small volume, but the outside area or the surrounding area is in bulk, it is in a huge volume. There would be a sufficient amount of material available for the heat conduction. Well on your screen you can see the hardness which is recorded or hardness which is measured for this disc which we have taken.

After the laser surface treatment, it was tested for the hardness and the graph is plotted which is there on your screen. Now, on x axis we have taken the distance of the measurement from the surface from the top surface and that is in microns. You can see that we are varying the distance from the top surface from 0 micro meter to about 1,200 micro meter 1.2 millimeters. The hardness value has been taken on the y axis.

Here the hardness was noted to be varying from about 200 HV value up to 1,000 HV value. All other parameters are varied as per the table which is shown in the previous slide; the power at two levels, velocity is constant, diameter is constant and then the trends were plotted which were there on your screen. Now, if you look at the trend for 1,300 watt, this is the trend for 1,300 watt the hollow square which are shown over here.

These values have been recorded for the 1,300 watt. Here you can see this is the graph for the 1,300 watt. If you look at this particular graph what we are observing is that when we are taking the hardness value at near to the top surface the hardness is very high. The hardness is around 800 HV value. 800 HV value is quite high; and as we move inside the workpiece along its thickness direction then there is a sharp decrease, sharp reduction in the hardness value.

And it comes down to about 200 HV value. Here the meaning is that the surface which is laser treated has changed, has enhanced its hardness property. 1.3 kilowatt at the surface to the depth of about 0.3 mm that is about 300 micron. Here you can see 300 micron and almost constant hardness of about 800 HV 0.2 was obtained. The hardness increased to 900 at 0.4 mm depth.

It was noticed it is increased for 0.4 up to 900 and followed by there is a decrease in hardness to 676 at 0.45 mm depth, 450 micro meter depth and there is a sudden drop, sudden reduction to 300 at 0.5 mm of depth and beyond that it has reduced to 250 HV value. At this laser power of about 1.3 kilowatt the surface temperature of about 1,200 degree Celsius at cooling rate of 4,500 degree Celsius which is very slow interaction rate of 0.18 was used.

And this transformed the original pearlite region into highly hardened martensite region. During this cooling operation with a cooling rate of 4,500 degree Celsius per second the original pearlite was transformed into harden martensite layer and due to that the hardness of the surface was enhanced. In this way by having the controlled irradiation of laser beam on the surface of metals we can enhance the hardness value of the surface.

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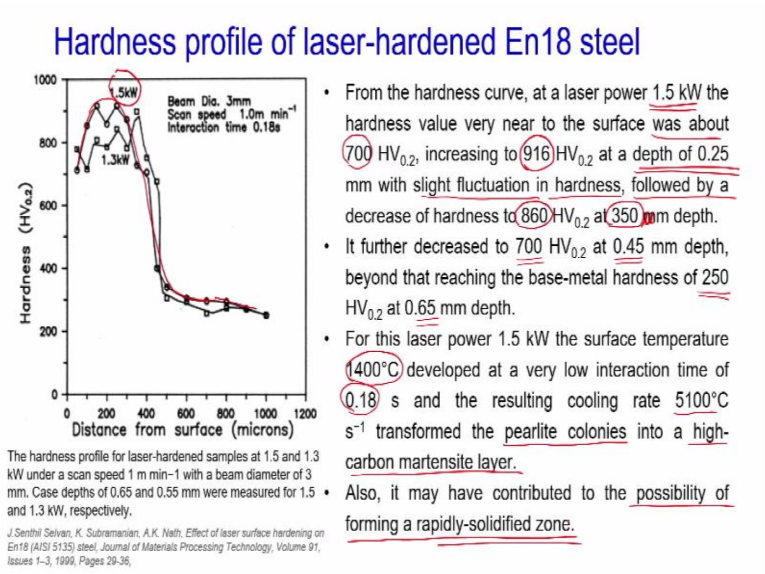

Now, let us take the second curve, the second curve is for 1,500 watt that is there on your screen and it has been shown by using circles. This is the curve for 1,500 watts. Again, the parameters were same the other parameters only the power we are varying here. Now, let us look at the observations that we got for the hardness curve at laser power of 1,500 watt the hardness value was near to the surface was about 700 HV at the surface or the volume or layer near to the surface the hardness was noticed about 700 HV value.

The maximum value was noticed about 916 HV at the depth of about 0.25 mm for about 250 microns with slight fluctuations in the hardness. Due to the different chemical composition of the material and the application of the force during the hardness measurement we may get certain fluctuation when we are using the indent type of hardness tester. It is also dependent upon the grain, the grain orientation if suppose the indentation is done in the voids that also affect the value of hardness.

There would be a slight fluctuation in the measurement of the hardness that also has been noticed over here. However, when we increase the depth further we notice that it was decreased to about 860 HV value at 350 micrometer depth it was about 860. When we increase the depth further to up to 450 micron that is 0.45 mm it was about 700 and beyond that it came down to up to 250 HV value for 650 micron.

Now, during this operation the maximum temperature was computed about 1,400 degree Celsius and the interaction time was very less that is 0.18 seconds and during this interaction time the heat input was given and later the heat was removed and there was a rapid cooling with a rate of 5,100 degree Celsius per second that transformed the pearlite colonies into high carbon martensite layer.

The pearlite colonies, pearlite content was transformed into high carbon martensite layer and that resulted in enhancement in the hardness value. Moreover, this enhancement in the hardness value was also noticed due to possibility of forming a rapidly solidified region. There is a rapid solidification during this operation that also led to have a hardened layer during this operation.

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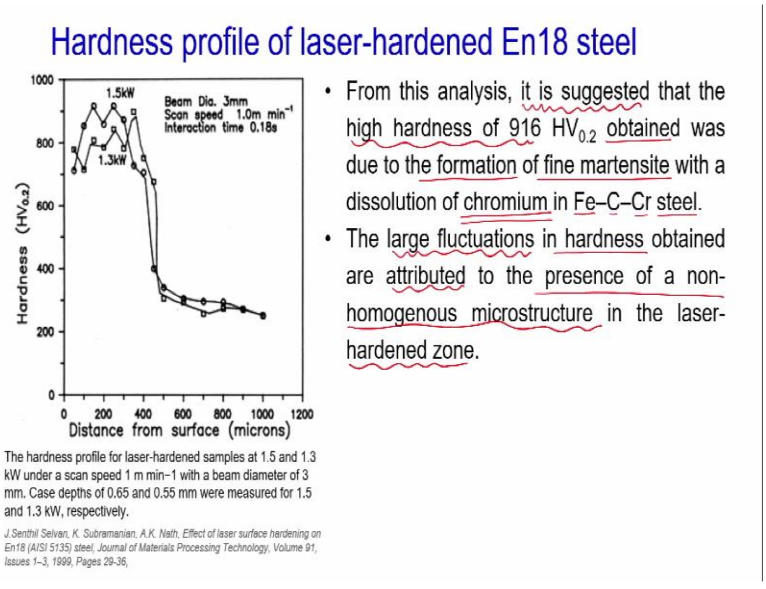

From this analysis we can say that this experimental study has suggested us that high hardness of about 916 HV value can be obtained and this is due to the formation of fine martensite with a dissolution of chromium. Chromium is also there in FE-C-CR steel so ferrous iron chromium steel due to chromium as well we got little high hardness during this operation.

We also noticed that there is a large fluctuations in the hardness obtained and it is attributed to the presence of non homogenous microstructure in laser hardened zone. The microstructure was not homogenous, it was heterogeneous and during the application of the load for computation of the hardness value if the indentation is at different location with different grains or the voids we may get different value of hardness. Due to that we got the fluctuations during the hardness testing as well.

Fine! The next parameter which was studied was the wear behaviour. When we are using the mechanical components when there is a relative motion between two or more components or parts or elements. There is a friction and due to the friction, there is wearing of the material, wearing of the parts and later this wearing of the parts will lead to inaccuracies in the job production or it may further lead to failure of the system itself.

Therefore, it is very essential for us to have a component with sufficient wear resistance property, but when we carry out the machining operation then there is a chances of having enhancement in the wear properties maybe due to cutting of the grains or the chemical composition of the material itself will have prone to the wearing due to its elements. In this case we can enhance the wear property by treating them with lasers. This we will be studying now.

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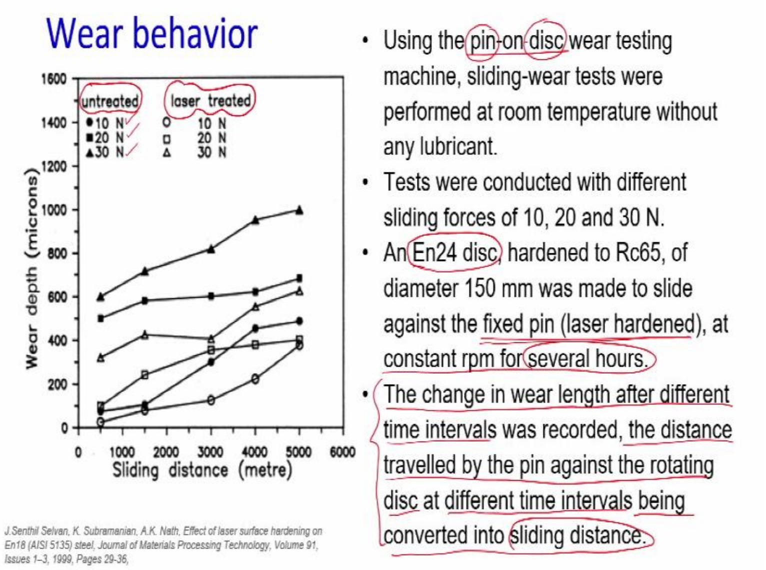

Here the wear behaviour is studied by using an instrument that is called as pin on disc instrument. So, name itself is suggesting we are using a pin and we are using a disc and we are putting the pin on the disc; disc is continuously rotated at certain RPM. There is contact of pin with the disc continuously during the rotation of the disc and due to this contact there would be wear of the pin.

By computing the weight loss of the pin during continuous rotation of the disc we can easily compute the wear resistance. If there is a more weight loss that will lead to less wear resistance. If there is a less weight loss the pin which is providing the pin is providing the more resistance for the wear. So, that is the basic characteristic. That we would like to verify or study for laser treated components as well.

Here we are taking two different pins the first pin is untreated means it is not treated by the laser and there is another pin that we are taking that is laser treated pin. By using these two different pins we are carrying out the rotation operation of the disc when the pin is in contact. It is not only in contact we can even apply fixed force on the pin so that load also can be varied.

Here we have taken three levels of the load 10 Newton, 20 Newton, 30 Newton. And these three levels of the loads is constant is same for both the cases untreated pin and laser treated pin. Here as we have already seen that we are taking the same disc that is EN24 and then we are carrying out this for our application. The fixed pin is the laser hardened, laser processed.

And then we are rotating the disc for several hours for a distance in 100s of kilometers for several hours we are rotating the disc and then we will see whether the part is getting warn out or not. During this process of operation we are noting down the change in the wear length after different time intervals. We are also computing the distance travelled by the pin against the rotating disc at this different time intervals.

And then we are computing the distance that is we call the sliding distance between the pin and the disc.

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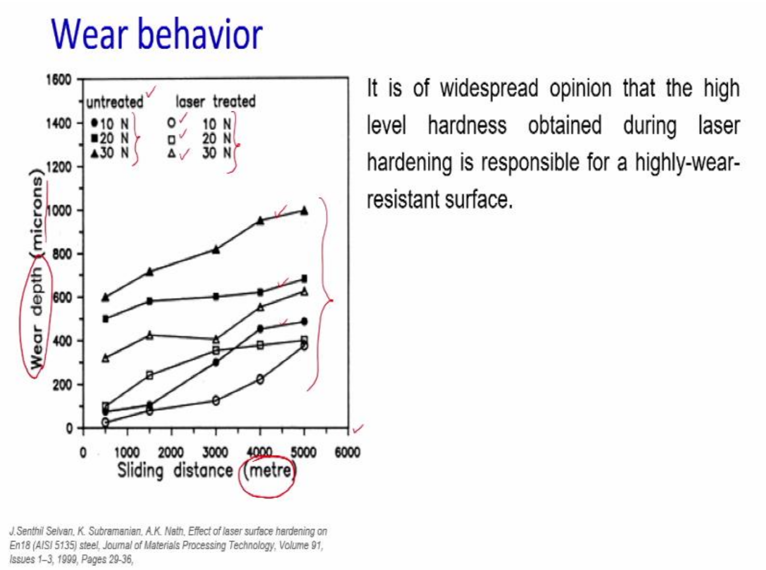

Let us study the plots that we got for the wear resistance. Here we are plotting the wear depth and that is in microns with the sliding distance that is in meters. I mentioned in my previous slide the sliding distance is computed by using the RPM of the disc and the time duration and the wear resistance is function of the wear depth. We are measuring the wear depth continuously by using optical microscopes.

And then we are plotting it against the sliding distance. Here you can see on the x axis we are having the sliding distance which is varying from 0 meter to about 6,000 meters is quite long distance. That gives the idea that for a long duration of time we have carried out this sliding operation. The wear resistance is measured and that is plotted on y axis it is in wear depth.

And you notice that the unit is in micron and the depth is varying from about 0 microns to 1,000 microns or it is up to 1,100 microns. When we see these trends, you just notice that field in circle, field in square and field in triangle they are designating the trends or the values for untreated pin. For untreated pin, laser is not used to enhance the hardness value. The empty circle, empty square and empty triangle is used to designate the laser treated pin.

Now, you observe the graph which are there in front of you. What we can notice that the fill in triangles, fill in squares and the fill in circles they are certainly having more wear depth. If you just look at this curve, this curve and this curve they are having more values these graphs are showing more values for wear depth the meaning is that more wear depth means less wear resistance.

The component is getting worn out very fast. In comparison with this if you just look at the points or the graphs which are having empty circle, empty square an empty triangle the wear depth values are low are all these cases. Here it can clearly noted that the laser treated pin is showing low wear depth that means there is enhancement in the wear resistance and this enhancement in the wear resistance is attributed to increase in the hardness or the hardened surface that we are getting due to laser heat treatment.

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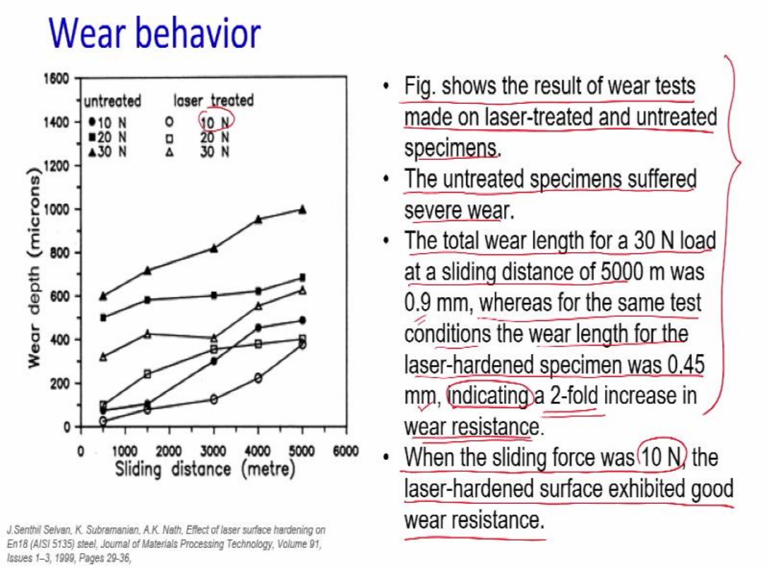

The same results are there on your screen as well. Here we can see the figure shows the result of wear test made on the laser treated and untreated specimen. It is obvious that the untreated specimens suffered severe wear. The total wear length for a 30 Newton load at a sliding distance of about 5,000 meters was 0.9 mm it is very significant, whereas for the same test conditions the wear length for the laser hardened specimen was 0.45 mm.

There is indication of two-fold increase in the wear resistance twice the value with untreated. Wear resistance is double for laser treated specimen in comparison with untreated specimen. When the sliding force was about 10 Newton the laser hardened surface exhibited very good wear resistance as well. For 10 Newton we got very good laser resistance and all the studies was conducted by a group of scientist which are shown at the bottom side of the slide.

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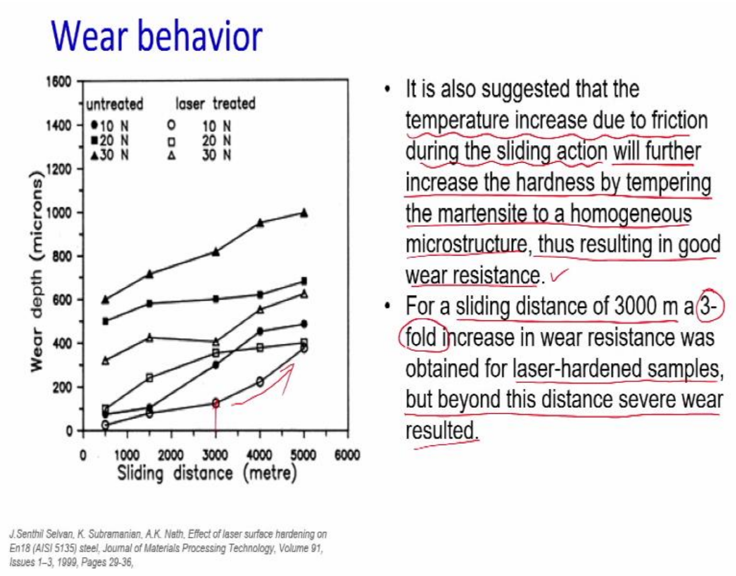

It is also suggested that the temperature increase due to friction during the sliding action will further increase the hardness by tempering the martensite to a homogenous microstructure which resulted in good wear resistance. It is not only the hard surface which we have used during the pin on disc experiment. The heat which is generated during the friction of the pin with the rough surface of the disc due to that heat there is a tempering was carried out.

And the tempering is generating a homogenous microstructure from the martensite and that resulted in very good wear resistance. So, both the factors are there the hardness of the laser treated surface plus the tempering which was done due to the heat of the friction as well. Now, if we look at a sliding distance of about 3,000 meters there is increase wear resistance value by three-fold in the laser hardened samples.

But beyond this distance there is a severe wear resulted. Here we got about disc for 3,000-meter distance. We got very good wear resistance value, very low wear depth and that is giving very good wear resistance value, but there is a sudden increase in the wear depth. There is a sudden increase in the wear depth which is indicating that the wear resistance is reducing.

And that maybe due to the sustainability of that laser heated surface at longer period of time. In this case we have to ensure or we have to carry out more research, we have to carry out more experiments and see how can we improve the wear resistance for the distance beyond 3,000 meters. For this you have to choose the laser parameters very meticulously, you have to carry out more experiments for this purpose.

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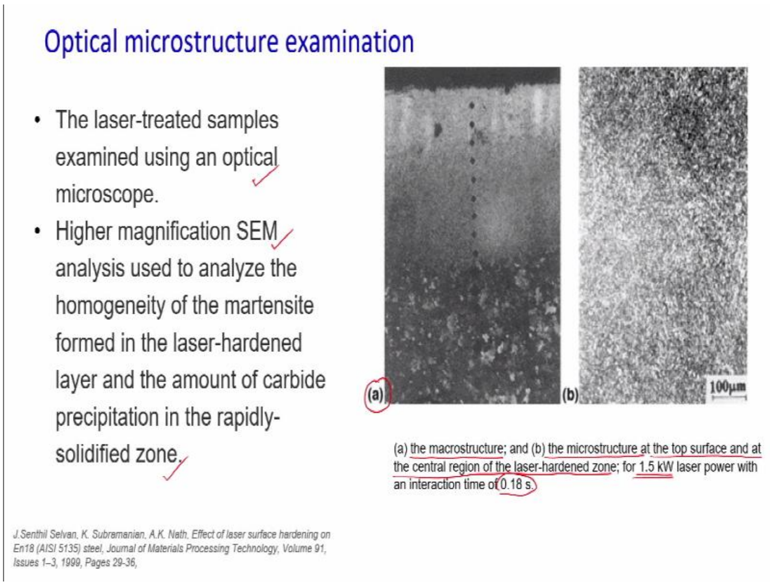

Now, let us look at the microstructure by using a optical micro graphs. On your screen you can see two different figures. The first figure that is a it is showing the macrostructure of laser treated specimen and the b is showing the microstructure at the top surface and at the central region of the laser hardened zone and these two pictures have been taken for specimen which is treated by using 1,500 watt laser and the interaction time was about 0.18 seconds.

The treated samples were examined using optical microscope and later the higher magnification SEM scanning electron microscope also used to analyze the homogeneity of the martensite formed in the laser harden layer and the amount of carbide precipitation in the rapidly solidified region. It is not only the optical microscope was used the higher magnification SEM that is the scanning electron microscope was used.

And the homogeneity of the martensite formed during this operation in the laser harden layer was studied.

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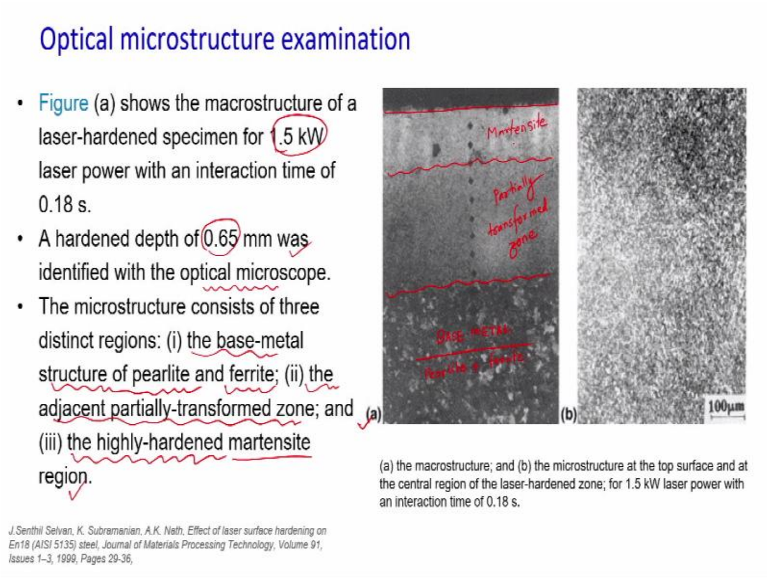

As I mentioned a it showing the macro structure and what we have noticed here the hardened depth of about 0.65 mm 650 micron was identified in the optical microscope. Hardened depth or the layer which is having sufficient hardness or enhanced hardness was noted about 650 microns. It was noticed that the microstructure is consisting of three distinct regions; the base metal which is having the structure pearlite and ferrite.

Second the adjacent partially transformed zone and the third one is highly hardened martensite region. During this optical micrograph study it was noticed that there are three distinct region. The first region is the base metal. This is the base metal which was noticed and this base metal is having pearlite and ferrite. There is a adjacent region where you can notice this is the adjacent region where there is a partially transformed zone.

So, this is the partially transformed zone and the top region which was treated by the laser is highly hardened martensite region. And this is martensite region which is highly hardened.

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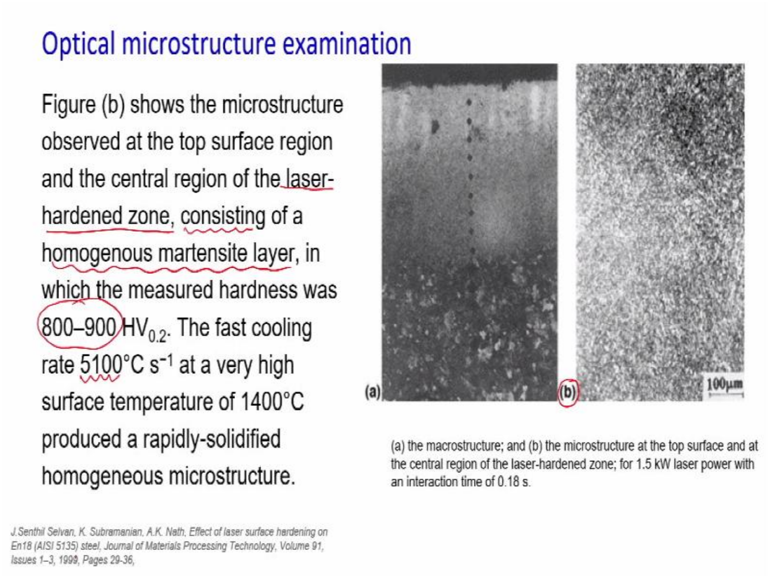

Now, let us look at the figure b or picture b. It shows the microstructure observed at the top surface region and at the central region of laser hardened steel. We are looking at the top surface and at the central region where the laser was applied and it shows a homogeneous martensite layer in which the hardness value was measured about 800 to 900 HV value which is quite hard.

And this is attributed to the fast cooling that we have already seen it is about 5,100 degree Celsius per second from a very high temperature of about 1,400 degree Celsius.

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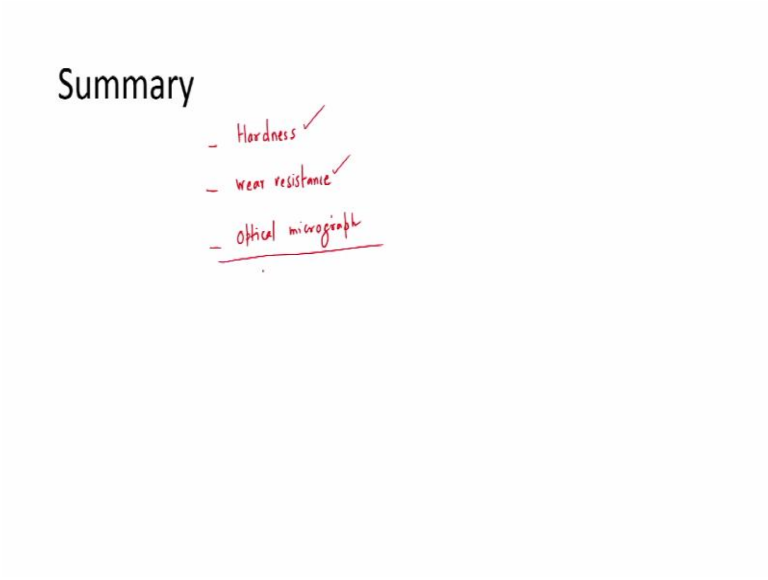

With this I would like to stop for today's class on studying the laser surface hardening. We have studied various results of applying the laser beam energy on three factors or three parameters that is the hardness, wear resistance and also we have seen the optical micrograph.

We have seen that hardness is increasing in laser treated samples, the wear resistance is also found to be increased during the laser surface processing.

Optical micrographs has given us the idea about the hardened depth during this operation. Overall we can say that lasers are quite useful to enhance the hardness value and the wear resistance value during laser based material processing. So, with this I would like to stop for today's class, today's lecture. In the next lecture, we will be studying few more application of laser in the surface treatment. Till then good bye. Thank you.