Surface Engineering for Corrosion and Wear Resistance Application

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Lecture – 23
Shot Peening and Rolling

So, welcome to the 23rd lecture of Surface Engineering. In the previous lecture we covered Short Peening where we used spherical objects to hit the surface and create limited deformation zone below the surface and in the process created residual compressive stress which enhance the fatigue life.

In this particular lecture we are going to cover a very similar approach of conventional processing, but using not projectiles, but very similar type of object solid objects. But the energy of or the velocity is not coming from the gas propelled or air propelled shots, but these energies kinetic energies are created by ultrasonic wave.

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So, that is why this kind of a process is called ultrasonic peening. So, ultrasonic peening or in brief the UP is a process where we actually again have the same intention of improving the fatigue life. Particularly for welded elements or structures in narrow zone not necessarily for very large surface areas by using ultrasonic wave as the a means of throwing or directing certain objects solid objects like this on to the surface of the particular region that we want to develop such compressive stress.

So, these are essentially very high frequency pulses which obviously, the very name ultrasound gives you the impression that we are talking about very high frequency waves. So, these waves basically creates certain mechanical motion kinetic energy and so, we target highly stressed locations in the weld and we want to modify the metal at the well junctions at the Wellmans at very shallow depth in typically atomic scales, this actually relieves the stress concentration and the so, called residual stress and increases the integrity and strength of the structure.

Now whenever we actually experience a solidification process. We all know that any liquid when it solidifies it tends to contract depending upon the coefficient of thermal expansion and when it contracts the state of stress on to the surface is tensile in nature. And so, any welded joint essentially is prone to cracking or failure because the state of stress on the surface is tensile in nature. So, we would like to reverse that we insist. So, instead of if this is the welded joint. So, if this is the weldment we would like to create a state normally after solidification this is the state of stress.

But we would like to reverse that and create a state of stress, which is opposite in nature. So, instead of positive we would like to make the state of stress negative or compressive in nature. So, this is quite possible in localized region using such ultrasonic peening. So, how the way we adjust our optimize the parameters we actually can produce necessary changes in terms of the residual stress, stress concentration and other mechanical properties and in the process improve the fatigue life.

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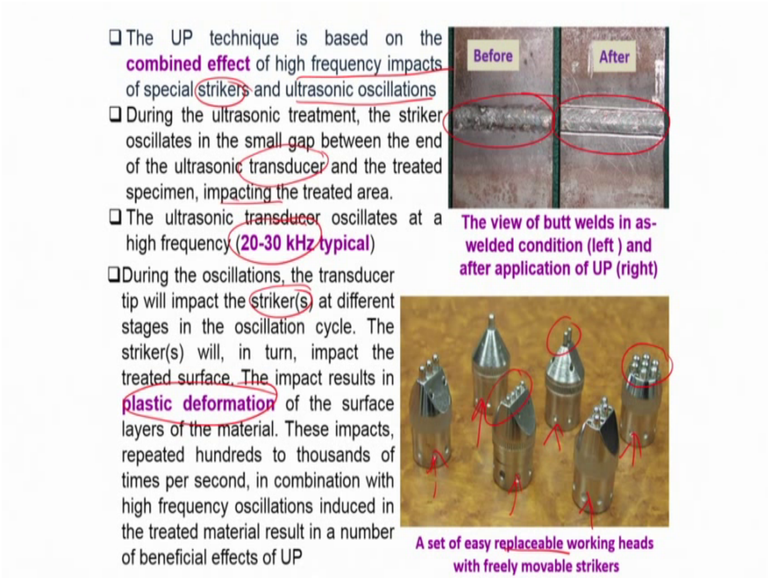

So, the implements instead of spherical shots what we use here they are called strikers and typically the strikers are actually they are propelled by this ultrasonic wave at very high frequency and they are responsible for creation of this plastic deformation. So, we actually are combining the effects of very high frequency impacts which are coming from the strikers and the ultrasonic oscillation that is happening at the background.

So, because of this ultrasonic oscillation which actually is created and transferred by the transducer that we have and at the head of the trance. So, there is a gap between the transducer and the surface on which we want to treat. So, this gap is partially filled by this strikers and because of the ultrasonic very high frequency wave created the strikers have no other option than to go and hit the surface at a certain level of and create a certain level of impact energy on to the surface.

And because of this in these impacts of successive impacts we treat the surface and create a state of stress. The typical frequency at which this kind of ultrasonic transducers or generators operate is a few tens of kilo Hertz and these at this very high frequency they when they impact they obviously, create a deformation zone which may be confined to limited area and limited depth, but is very effective to create a reasonable amount of deformation and plastic strain below the surface.

So, these are the various types of heads which are used and these are replaceable. So, whenever there is certain deformation of these heads, we can change them and just from the bottom we actually allow the ultrasonic waves to actually propel these strikers or striker heads to go and hit these kind of welded joints.

So, a welded joint in as welded condition if it appears like this after such shock peening they will actually appear very uniform and if you actually measure the residual stress by let us say X ray diffraction, then you will find that the state of stress is negative or compressive in nature.

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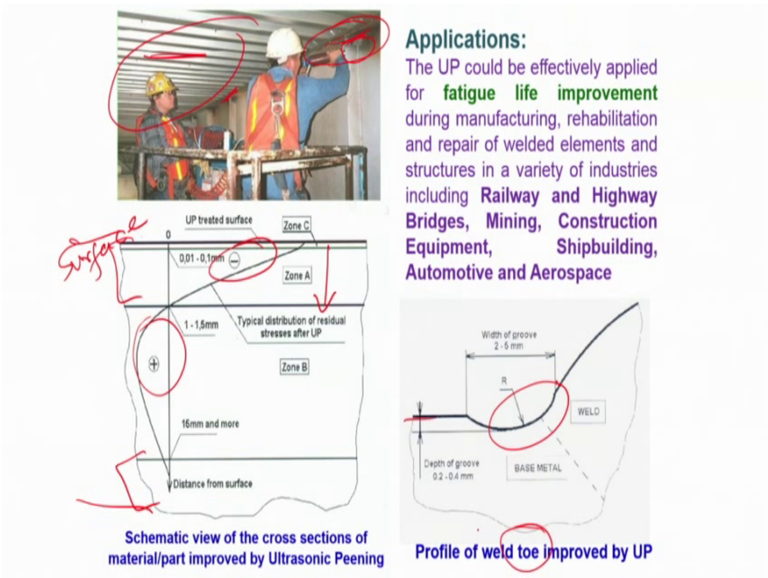

So, the advantage is that in cases where for example, in a construction activity where you actually had to weld corner or treat certain portions here or right on the rooftop. So, in such cases you cannot dismantle the whole roof here or you cannot dismantle the joint at the corner and then take it to a machine and do a ultrasonic peening or for that matter any other kind of peening.

So, in order to actually extend the life of such welded joints at this difficult to access corners or large surface areas and so on. You actually all you need to do is to take the gun the ultrasonic peening gun and then create this treat the surface and create this state of stress. So, if this is the total thickness that we are talking about of a particular sheet then this region and this region actually may actually develop a stay.

If this is the depth direction then this is and this is the surface. So, we actually would like to create a state of stress which is negative or compressive in nature up to a certain depth from the surface. And even if the bulk inside or the interior is actually at a tensile mode of residual stress it does not matter.

Because crack opening if at all happens should reach the surface or propagate through the surface then only the failure can happen. Now a while talking about difficult to access regions for example, this corner the root of the weldment is also very important. In fact, is more important than the rest of the weldment.

So, using this ultrasonic peening you actually can access it better than shot peening depending on the striker size and so on, you actually can treat these regions very well and create state of compressive stress at this door or the root of the weldment.

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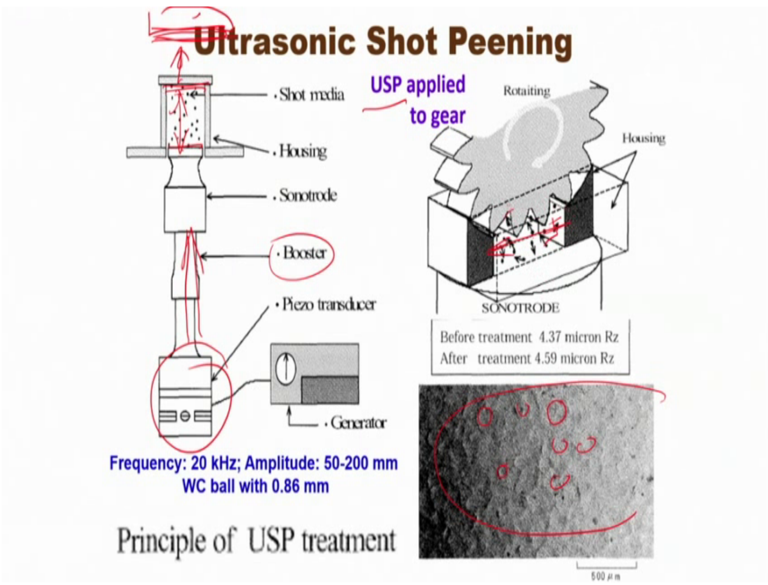

So, this is the typical machine and so, this is where you generate this is the generator and so, this is how you feed the frequency you create the ultrasonic waves here you are connected to this generator a portion the basic head of the transducer. And that transducer transfers the frequency at very exactly the same frequencies transferred through the booster or actually is made even higher through the booster. And eventually this is where you create this kinetic energy and motion and you can use either shots or the other strikers which could be needles or peens and so on and which.

So, there is a very little gap between these two and this is the gap which actually is very crucial because this is what will determine the intensity with which the shots or the pins or the needles will hit the surface and then this is where you treat the surface this is where you create the certain. So, the shots come out and this is where the object is and this is where you actually create this mechanical deformation. So, the surface after deformation may look somewhat like this. So, you can easily make out that there are certain regions certain undulations created onto the surface and these waviness is because of the impact of those shots.

So, actually you can create for example, this large gear piece can be actually treated by ultrasonic peening then you expose it just to this opening. So, this is the opening through which the ultrasonic wave can actually hit these gear teeth and then create the regrets state of stress.

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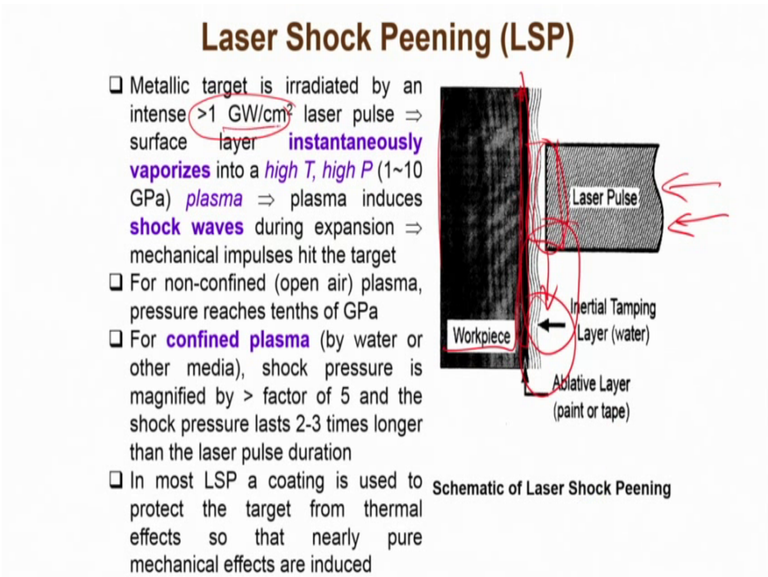

So, in either shot peening or ultrasonic shock peening, where the propulsion is purely coming from the ultrasonic waves. In both the cases there is a physical contact of the shots or the needles or the pins or wires or whatever we are using. In certain cases where we do not want to see such localized deformation or indentations or ripples created we want the deformation zone to be wider and not developed such typical indent indentations.

We actually can go for a more sophisticated technique where we use targeted laser beam of very high power density typically Giga Watt per centimeter square, which are actually. So, first of all if this is the work piece. So, this is the work piece that we have and we actually cover it up with a particular tape or some other coating and then we use a laser pulse to heat the surface. So, actually the size of this laser spot is very very small maybe at the most of you millimeters, but when it hits the surface and actually you expose or irradiate this region at one instant of time and then you move either up or down and then the next region is irradiated and there could be always some amount of overlap of regions that are irradiated.

So, even if the laser beam is small, but you actually can cover a much wider or longer surface area. So, when you expose and when you irradiate such very high power density on to the surface. So, instantly a coating that you have below the tape or the cover gets vaporized and when it gets vaporized it would; obviously, try to expand because of the prevention or because of the cover that you have applied on the other side.

So, the wave that is created between the tape and the work piece. Now experiences an extremely high level of shock wave and this shock wave is able to deform very little depth from the surface. So, the amount of deformation that propagates is smaller and when you actually irradiate the smaller zone with very high load. So, the effective stress that actually works on this is much higher than what you can experience in case of ultrasonic peening or shot peening.

And as a result you actually can create a shock pressure which is much higher by a factor of 5 or and also can last 2 to 3 times longer than the laser pulse duration. So, in other words if the pulse duration is for a millisecond or microsecond the effect lasts for longer period of time and if the beam diameter is let us say 1 or 2 millimeter the area that is affected is wider than 1 or 2 millimeters.

So, actually that is how you can move over the surface and integrate over the entire surface area. Now so, its not the thermal effect of the laser that is important or that is what is going to make the changes on to the surface of the work piece, but the shock wave that you generate because of rapid vaporization of the coating or thin film that you actually have applied and then covered it up with it with the certain tape or some other confinement mechanism and usually to make this confinement even more effective.

So, that the shock wave created by that so, called plasma or simply the gaseous state of that substance you actually can have it in an immerse condition; so, immersed in water or some other medium. So, confinement of the plasma gives more effect or increases the effect of such shock waves and creates the residual stress or initially the deformation part which is responsible for creation of residual stress that. So, that is higher because of the confinement of the plasma.

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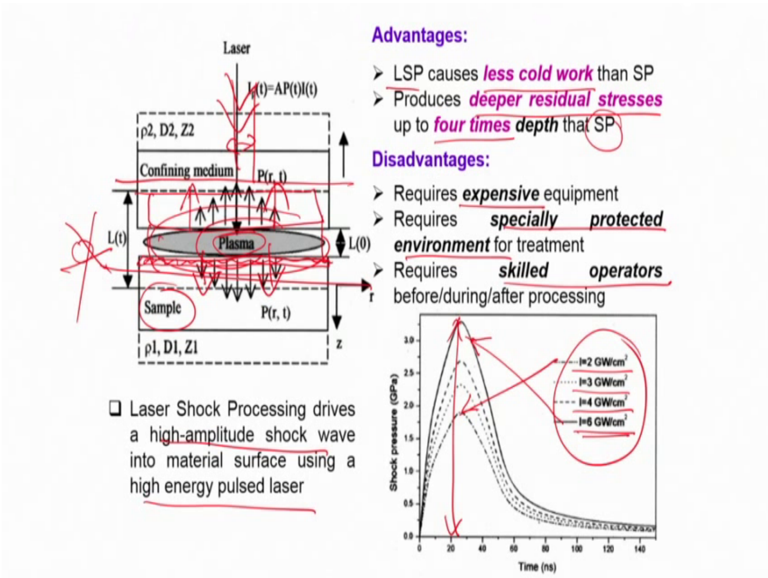

So, this is what I was talking about that this is the sample and this is the film that you have which is going to vaporize because of the irradiation of the laser coming from the top and the immediate vaporization actually can create a very transient plasma very shot leaving plasma.

But this plasma immediately after it is generated would definitely like to expand. So, it would like to expand in both the directions ok, but since this region is confined and this is a rigid body. So, the plasma is going to transfer its energy by way of creating deformation of very shallow depth on to this work piece. So, this region this is typically the process we follow for all other peening processes right be it shot or shock peening or whatever.

The difference here is that there is no individual object which is hitting the surface, this is not the case here we have a plasma which is much wider than the simple laser beam. So, if the beam is only of this diameter we actually are covering a much wider surface region and this region is going to create a shock wave which is going to cover a much wider area.

So, the affect it is felt over a wider surface area and the amplitude of the shock wave that we generate is a much more intense because of the high energy pulsed laser. So, typical advantage of laser shock peening will be the depth of the cold work that we generate is less, but because the intensity of the plasma is higher we actually produce deeper residual stress which could be 4 times the depth of residual stress that we can create through the shock peening. So, its in a very more effective than shock peening and certainly more effective than shot peening.

The disadvantage is that its a fairly expensive equipment because laser is an expensive. So, the capital cost is very high operating cost may not be very high, but you require a fairly high skill set to be able to manipulate well and cover or integrate the entire surface area you require a protected environment because you know very well that laser can penetrate almost any solid certainly human eye. So, one has to take enough precaution in terms of chamber and goggles and so on.

But we also require operators who are trained who are skilled enough to use this kind of a sophisticated technique. So, depending on the effluence laser effluence or power density we actually so, for example, this is what is going to happen when you have 2 Giga Watt per centimeter square and compared to that when you apply a 6 kilo watt per centimeter square the shock wave or the shock pressure that you generate and particularly the amplitude the maximum pressure that you can generate will be much higher.

So, this is a very major process parameter the power density of the laser pulses the next important thing of course, is a pulse width since we are talking about power density. So, the exactly area of the spot is not so important. Then the you have to choose the right set right kind of coating here film here which actually can instantly generate the plasma and that plasma should be nonreactive and then if you are also able to use a confinement. So, that the plasma so, that the pressure created is mostly applied on to this direction on to the work piece then in the other direction then obviously, you a derived a bigger benefit.

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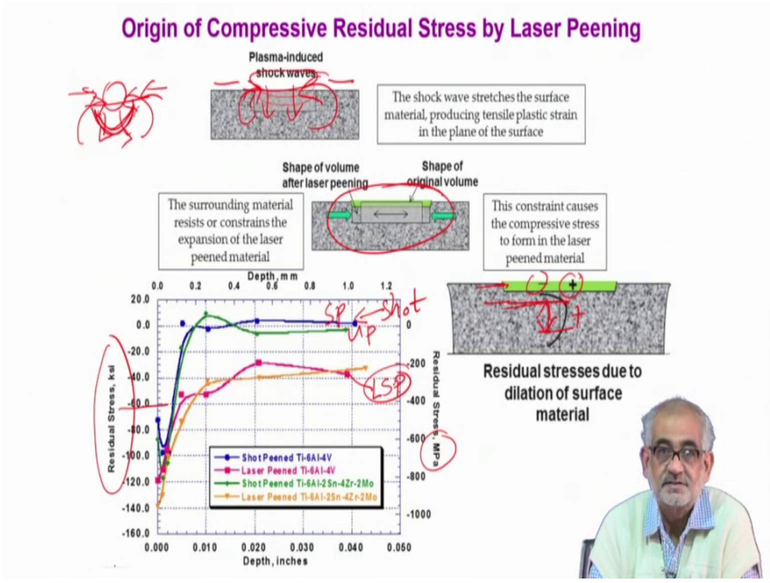

So, just like shot peening in case of shot peening we are even shock peening when the striker hits we saw that this would be the deformation zone below the object which is incident on to the surface or the projectile onto the surface. And so, initially this is how the material will tend to deform, but then subsequently the material wants to come back and spring back and that is how we create state of a compressive stress onto the surface.

The same thing happened in case of a plasma induced shock waves. So, instead of a physical object hitting the surface its the shockwave created through this plasma which actually tends to deform. So, it tends to deform here and exactly because of the reaction to such tendency of deformation you create a state of stress which is towards each other not away from each other so; that means, you create negative stresses or compressive stresses.

So, this is exactly the mechanism that is followed and as a result this is the tensile side and this is the compression side. So, on to the surface you actually have a state of stress let us say up to this depth which is negative in nature compressive in nature and below that in the interior you may have positive state of stress, but again on to the other side if this side is also treated we will also develop negative state of stress.

So; that means, a sheet of a finite thickness can actually develop a state of stress which is compressive in nature onto the surface where the core may still be at a relatively tensile state of stress which is certainly not going to make any difference. Now if you compare the different methods of peening so, for a given material the same material the if we compare the state of residual or the magnitude of the residual stress created in terms of ksi or in terms of mega Pascal then what we see is that if the process if the peening method is shot peening.

So, this is where we are if the method is laser peening then this is where we are. So, what we understand is that either shot peening or ultrasonic shock peening or ultrasonic peening the magnitude of the residual stress that we develop in case of laser shock peening is much higher that is and also deeper. So, both these effects are very very beneficial.

So, if you compare the between the three possibilities that we have discussed shot peening ultrasonic shock peening and laser shock peening then; obviously, laser shock peening is the most precise more most effective, but is more sophisticated and hence is more expensive.

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Now, one another type of possibility of introducing such residual compressive stress onto the surface could be simply deformation. Now either you hit with the projectile or hit with ultrasonic I mean a striker propelled by an ultrasonic wave or a laser or a plasma shock created by vaporized ultra fast vaporization through a laser irradiation. In all these cases we essentially are trying to deform, essentially the net effect is certain deformation onto the surface up to a certain depth. Now I can easily deform without going into all those processes I can also deform if I simply roll the material.

So, if I have a certain stock of a finite thickness and if I pass it through two rotating rolls and if we pass it below and if the material has a thickness greater than the gap between the rolls then; obviously, there will be deformation. And if this gap is nearly about the same as the thickness of the material then the deformation layer will penetrate only skin depth from the surface.

So, that kind of a rolling with controlled deformation is called Skin Pass Rolling SPR. Now when we actually employ such skin pass rolling this is nothing, but a cold deformation process mechanical in nature and actually it can have a significant effect or in terms of the mechanical properties, on the by way of prevention of Luder's band creating strip flatness if there are waviness it can be corrected if there is some surface topography which is not beneficial or desirable we can take care of up to this.

So, the process requires application of little bit of lubricant or you can do even dry friction rolling use relatively lower power, but so, that the deformation zone actually is confined only to the surface or near surface region.

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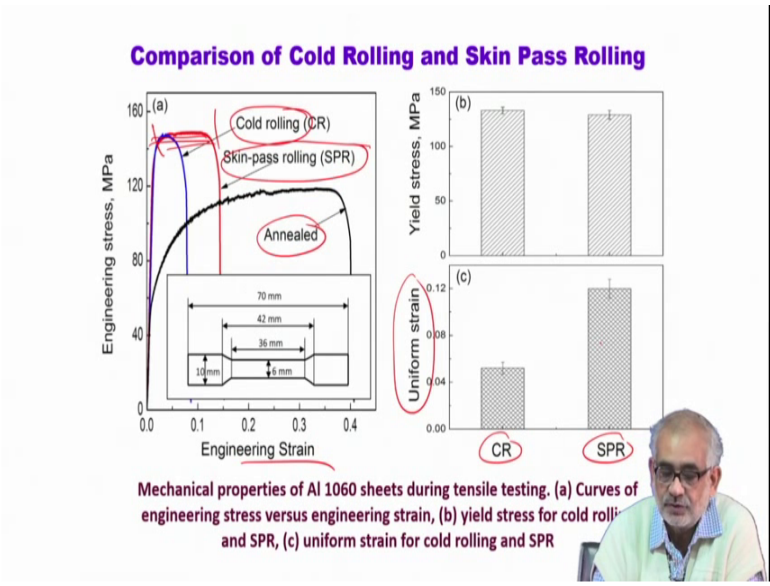

So, if you compare an a steel fort for that matter in a needled state in cold rolled state and in skin pass rolled state then and if you compare then you realize that when you compare cold rolled state with skin passed roll state the yield stress will be about the same there is hardly any difference in the yield stress. But the total the plastic the strain the uniform plastic strain that you actually derive after skin pass rolling will be higher.

So, the yield stress remains the same, but the ductility are so, called plastic deformation that amount of engineering strain is more and this is certainly beneficial. So, skin pass rolling is going to be helpful because of this particular effect.

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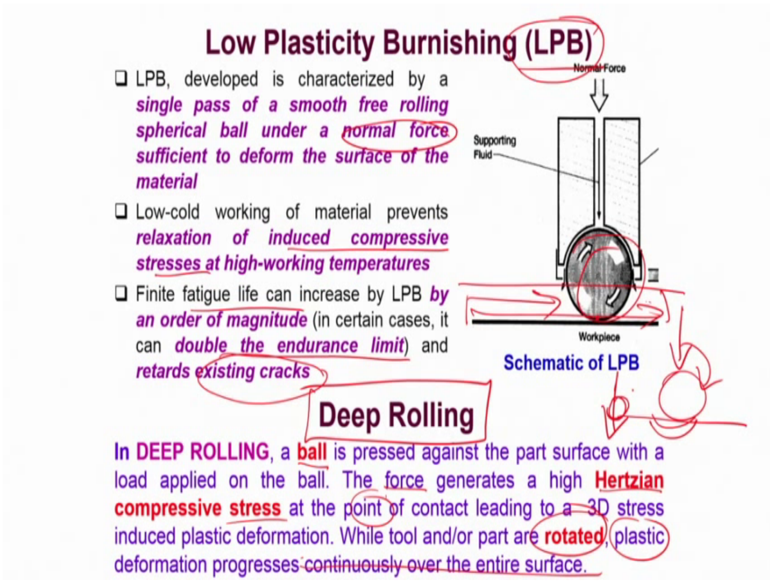

So, this is a typical machine where you have multi strand roll you actually can control very well exactly the amount of pressure that you are applying and hence the depth of deformation and also the rate of deformation. So, you actually can produce a smooth surface of uniform thickness you can lock the dislocations whatever you create onto the surface and also can reduce the yield point phenomena the Lewis band. So, we do not want. If this is the stress strain curve, we do not want to create such Luder's band and then in the plastic zone.

So, this kind of striations at upper yield point lowering point phenomenon can be reduced or prevented and the state of stress can actually or the plastic curve can actually deformation curve can be fairly smooth because of such skin pass rolling. It also helps in removing the defects known as strangles which are very commonly occurring on the surface you develop certain contours certain defects typically appearing like a fractal or spangled onto the surface, so, in a wider surface. So, you can of a remove this kind of situations or defects by way of this skin pass rolling.

One last important technique that I would like to mention in terms of this kind of surface deformation aided processes for improving the fatigue strength is the low plasticity burnishing. So, you simply have a roll you have actually you have a roll of you have a spherical ball. So, the contact is a very point contact and it simply rolls over to the rolls over the surface.

So, it moves for example, say left to right and covers the entire length of the sample. So, when you when this spherical ball moves over rolls over it actually rolls with a certain amount of stress already applied onto the surface. So, as a result it creates again limited deformation onto the surface and induces compressive stress and this actually or actually it can relief also a certain amount of state of stress if the temperature is high.

The fatigue life can be improved by substantially it can be improved it can even double the endurance limit and retard the cracks already existing onto the surface by way of this low plasticity burnishing. So, we are aware of the burnishing of a wooden objects. So, where basically you have a certain fluid and the Waksman polishes the surface with this fluid and that actually creates not only goes good or nice aesthetic look, but also creates a state of stress which actually is a beneficial.

But this burnishing is through a mechanical means where the ball rotates onto the surface with application of certain amount of normal force which creates a very thin deformation layer onto the surface which goes on creation of certain compressive stress or at least prevents relaxation of compressive stress onto the surface.

So, it can turn the tensile into compression or it can actually prevent relaxation of compressive stress created by some other processes. The last thing that I want to mention is called deep rolling and this is where you actually press the ball against the surface that you want to treat at a fairly high generate a fairly high force and a very high Hertzian compressive state of stress is created at the point of contact where the ball actually contacts the surface.

But compared to this where it move from one end to another during this rotation while the ball rotates here and it moves from one end to the other here the object that we are rotating the spherical object that we are rotating that is rotating at a particular rpm with simultaneous application of force.

So, this is the object which is rotating at very high rpm and at the same time there is a state of stress applied on to that. So, there are multiple rotations at while the while the ball is moving over the surface. So, the degree of deformation is larger and this can continuously progress over the entire surface area. So, this deformation plastic deformation will be deeper and hence the residual stress that you develop would be a greater in amplitude and deeper in depth.

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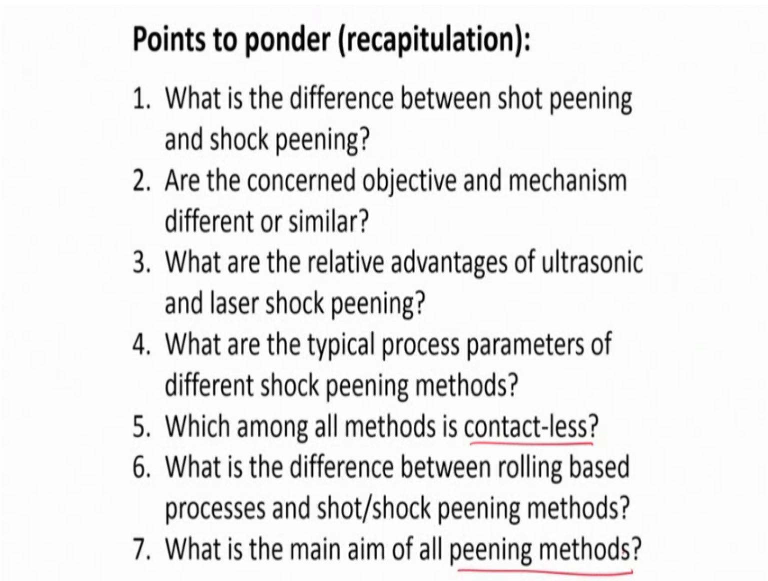

So, time to recapitulate. So, what we all what we have discussed so, far is the processes which are related to surface deformation limited surfaced formation leading to creation of residual compressive stress on to the surface. So, we discussed shot peening in the previous lecture and now we discuss ultra shot ultrasound propelled shock peening.

We also discuss laser peening, but we did compare the various mechanisms and relative efficacy of a one process to another in terms of the amplitude of stress created, the effectiveness of the process, the overall kinetics of the process, but also the relative ease or difficulty associated with the process we certainly realize that laser shot peening is much more sophisticated.

But; obviously, brings in a certain dividends which are not possible by shot peening or ultra sound peening. As I said the laser peening is a contact less process and whereas, the other ones are all requiring deformation which are through certain impacts physical impact of either shots or the pins or the needles and so on.

So, the main message of all these processes of peening processes that we have discussed is to a beat on a welded joint or simply a rolled sheet or a cast product or a rotating part a shaft or a beam or gear or ball bearing and so on. In all these rotating parts which are likely to fail by way of a fatigue this kind of surface deformation processes actually can introduce up to a certain depth limited deformation zone which will create in turn a state of compressive stress on to the surface and in the process can extend the fatigue life and reliability of the component.

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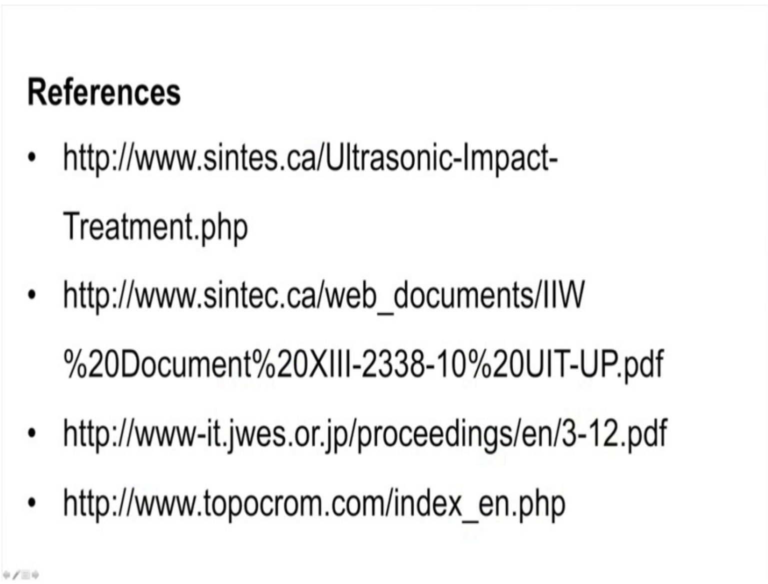

So, that that is how they are very very useful.

So thank you very much.