Laser Based Manufacturing

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Module # 04

Lecture # 12

Mechanisms of Laser Forming

Hello friends. I welcome you all to the second lecture of Week 4 of NPTEL online course on Laser Based Manufacturing. In this week, we are studying laser forming, various mechanisms of laser forming, process parameters involved in the laser forming, its advantages, disadvantages and various applications.

In the first lecture of this week we have seen the limitations of the mechanical energy based material forming processes and how lasers can help to eliminate some of the limitations or how lasers can help to resolve some of the issues related to mechanical based material forming.

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In today's lecture, we will be studying various mechanisms of laser forming. In previous lecture, we have seen one important mechanism that is temperature gradient mechanism. In today's class we will be studying two more important mechanism of laser forming that is buckling mechanism and upsetting mechanism. In addition to these two mechanisms we will also look at some of the applications of the laser forming in the industry.

Now, let us begin our discussion on buckling mechanism.

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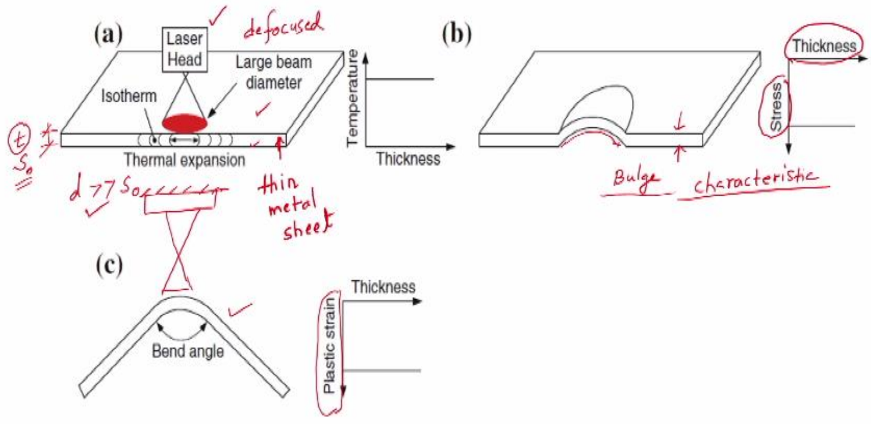
Buckling mechanism



a Temperature isotherm due to laser irradiation.

b Growth and development of buckling due to uniform thermal stress along the thickness.

c Final bending occurs due to buckling.

This is the second mechanism which is used in the industry and the schematic of the mechanism is here on your screen. You can notice a thin sheet, you can notice a thin metal sheet which is to be processed by using lasers. This is the laser head and you notice a defocused laser beam on the work part. This is defocused laser beam on the work part and you notice the diameter of the laser beam at the spot is very very large. The spot diameter is comparatively large with the thickness of the sheet, designate this thickness by S_o. Here the characteristic is that the diameter D is very large in comparison with the thickness. Now, when such situation occur for constant power, if we check such a large beam of spot diameter in comparison with thickness then naturally we are getting a constant temperature across the thickness. The temperature at top fibers and bottom fibers would be same because the thickness is less spot diameter is very high and the laser power is constant, speed is less and for such process condition there will not be any temperature gradient between the top fibers and the bottom fibers.

Now, let us see what are the stresses which are generated during this buckling mechanism. Here you can see if we plot the stresses we will get a constant stress profile with respect to thickness. Along the thickness the stresses are constant, uniform and we get sort of bulge at the top surface. This is the bulge and this is the characteristics of buckling mechanism.

When the stresses will get converted into plastic strain, then we get the natural bend angle and this bend angle is away from the laser beam in this case. On your screen you can see that the bending has occurred away from the laser beam. But that is not true always, in certain cases we may also get the bending towards the laser beam as well, since in stochastic and a random way the buckling mechanism behaves during the laser forming. We get the temperature isotherm due to laser irradiation and then there is a growth and development of buckling due to uniform thermal stresses along the thickness direction and we get the final bending due to the buckling of the sheet metal.

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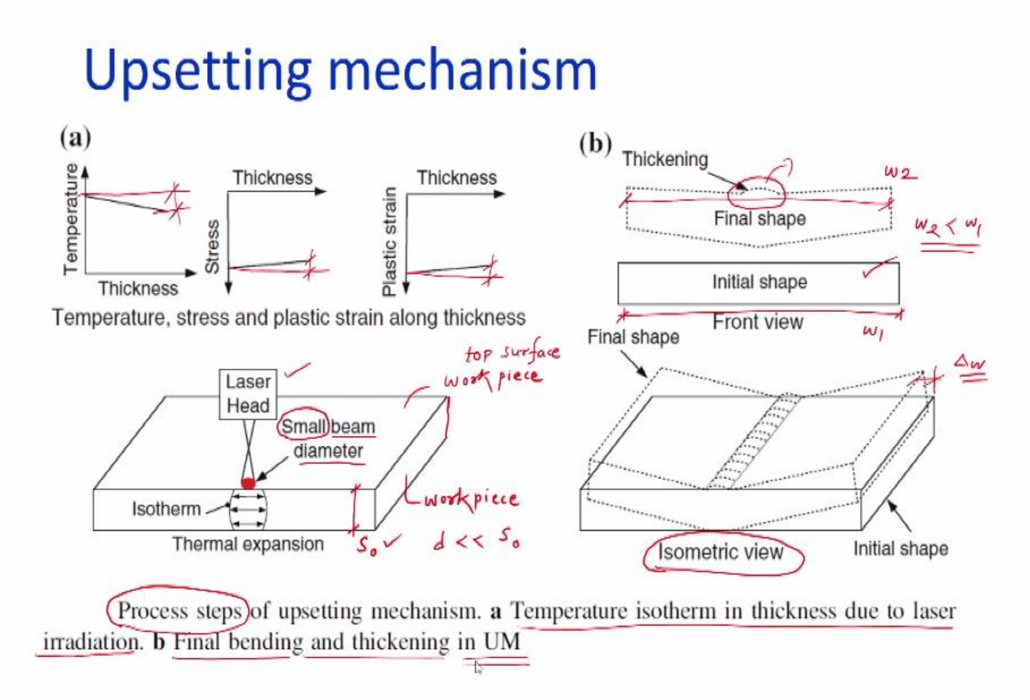

Now, let us look at the third variant of laser forming mechanism is upsetting mechanism. Till now we have seen temperature gradient mechanism and buckling mechanism. Now the third one is the upsetting mechanism. On your screen you can see the workpiece material and you notice that the thickness is quite high and we are having a laser beam, the laser beam is providing a defocussed laser on the top surface of the work part. But if you notice the diameter of the laser beam it is comparatively very small. I can write here the diameter of the laser spot is less than the thickness of the sheet. When such situation is there then we are not getting any prominent or a large bend angle during one scanning. In this case we are continuously applying the laser beam for multiple number of times, multiple number of passes and then we get little bit of bend angle with thickening at the spot of the laser beam irradiation. There is a bead formation and this bead formation is due to the local strain hardening. When there is a swelling or the bead formation at the application of laser beam there is reduction in the width of the work part and it is used for the correction of the plates.

Here you can see that we have continuously being applied the laser beam and during the application of laser beam there is thickening is getting occurred. There is little bending of the work part with respect to the initial shape. However, there is reduction in the width. This is the final width of the work part w2 and this is the w1. w2 is less than w1 and this reduction is attributed to thickening at the laser spot diameter.

What is the application of such upsetting mechanism? This application is that when we want to reduce the width of some thick plates without cutting it. Consider there is a plate of around 200 mm and we want to just reduce it to 198 mm. So, 2 mm we need to just reduce the width. In that case it is not possible to cut the edge by using any mechanical cutting tool because the width of the cutter maybe more than 2 mm it may be 5 mm or 10 mm. When we are using a mechanical cutter of 5 mm, certainly we will not get a 2 mm of cut. For this purpose we have to use such kind of local shortening method by using the upsetting mechanism.

This is the isometric view of the upsetted work part due to the continuous laser irradiation for multiple number of times. Here you notice there is a slight reduction in the width. This is delta w is quite small and expected that is desired during this operation.

Now, regarding the temperature, stress and the strain graphs are concerned, there is not much difference between the top surface and the bottom surface temperature that the same thing with respect to the stresses and the strain as well.

I would like to revise here the various steps. We get a temperature isotherm in thickness due to laser irradiation, then final bending and thickening is occurring in upsetting mechanism.

Now, let us compare various forming mechanisms.

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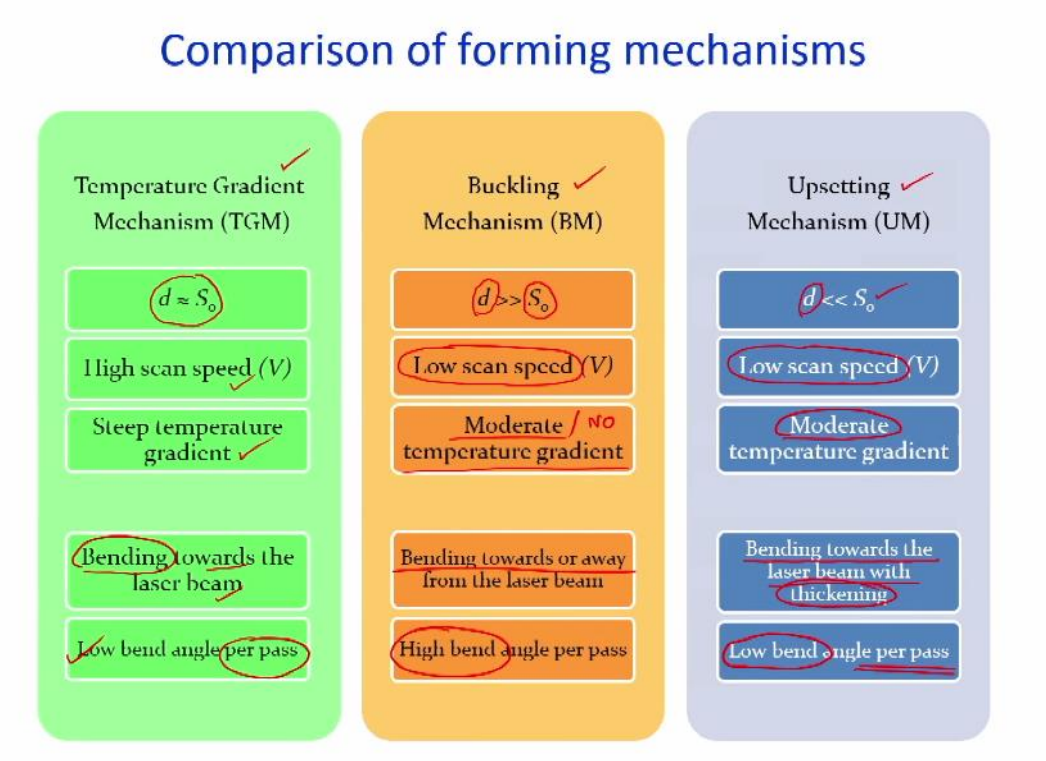

On your screen you can see the three mechanisms that we have seen, the TGM (temperature gradient mechanism), buckling mechanism and upsetting mechanism. If we look at the relationship between the diameter of the laser spot and the thickness, we can note here the diameter of the laser spot and the workpiece thickness is almost equal in TGM. In buckling mechanism, the diameter of the laser spot is very high in comparison with the thickness. In upsetting mechanism, the diameter of the laser spot is comparatively low with the thickness of the sheet.

To get sufficient gradient or to get the steep gradient of temperature in TGM we are using high scan speed we have to traverse the laser at a rapid speed. However, in buckling mechanism, to have uniform temperature at top and bottom surface the scan speed should be low so that there is a sufficient interaction time of laser with the work part. The temperature at top surface and bottom surface would be same and then and then only we can get the buckling of the metal sheet. In upsetting mechanism as well there has to be a low scan speed because we want to have the bulging or thickening of the laser spotted area and then and then only we can get reduction in the width of the work part.

We have seen that in TGM there is formation of steep temperature gradient or steep temperature gradient is essential to generate the TGM based laser forming. In case of buckling mechanism the moderate temperature gradient or I would like to say here there is no temperature gradient. In buckling mechanism there is no temperature gradient literally. However, in upsetting mechanism there is a moderate, there is a little temperature gradient with top surface of the work and bottom surface of the work part.

In TGM, the bending of the work part is towards the laser beam. However, in buckling mechanism the bending may occur towards or away from the laser beam. In upsetting mechanism, the bending will occur towards the laser beam and there is a thickening as well, that we have seen. These three characteristics you can see in TGM and UM the bending will occur towards the laser beam, but in the buckling mechanism it may happen on either side towards or away from the laser beam.

As far as the bend angle, that is the product of this laser forming process, the bend angle per pass is quite low in TGM; we are getting 1 degree bend angle per pass. However, in buckling mechanism we are getting a very high bend angle it maybe in the order of 5 degrees or 10 degrees bend angle per pass we can achieve. In upsetting mechanism as well the bend angle is quite low per pass.

After studying these three mechanisms one can choose or the process planner or the production engineer has to choose the appropriate forming mechanism for the intended application. If suppose you want to carry out very precision bending operation by using laser and you want to have the controlled deformation then you should go for TGM, but it is giving a very small bend angle of say 1 degree per pass. By applying multiple passes you can achieve the large bend angles. When it is not essential to have the control over the bend angle we want the maximum deformation in the metal sheets, naturally we can go for the buckling mechanism and certainly the upsetting mechanism is there to reduce the width of the laser process part.

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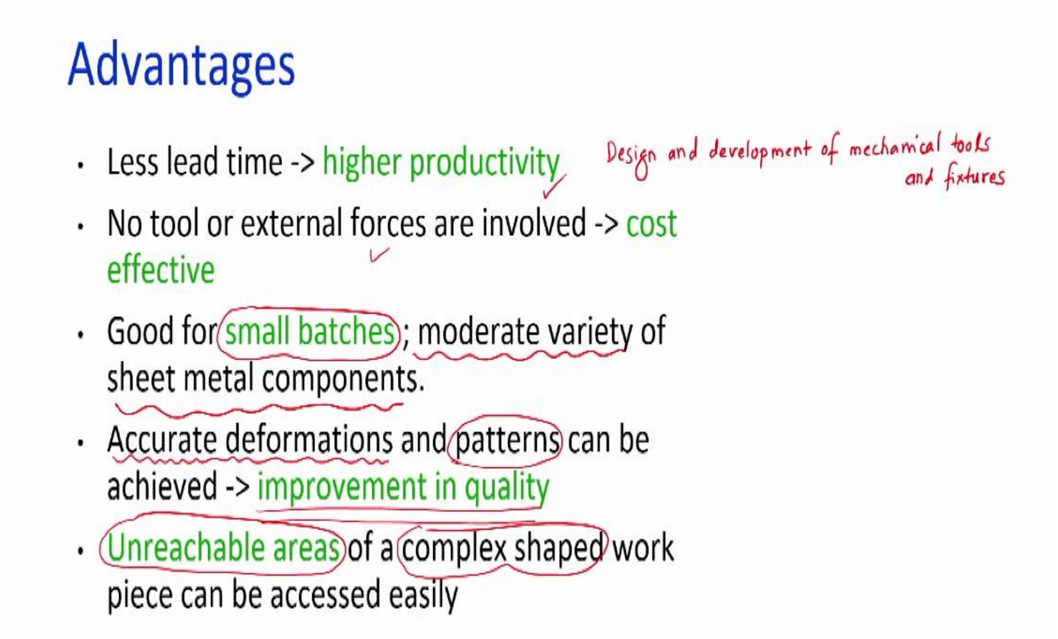

Now, let us study various advantages of laser bending or laser forming. The first advantage is less lead time. Here the lead time is associated with design and development of the tools which are required. Design and development of mechanical tools, fixtures and due to this there is high productivity. As the product lead time is less, certainly it is affecting positively on the productivity of the process.

There is no tool or external forces which are involved. It is that way cost effective process, no external forces are being applied during the laser forming process. The laser based forming is very useful when we are working in small batch of components to be processed not in a mass scale or in a continuous fashion for a batch of about say 20 or 25 pieces to be processed on urgent basis. In that case this laser based forming is a very good option and moderate variety of the sheet metal components can be easily accommodated, a small batch with moderate variety can easily be accommodated, can easily be achieved during the laser based forming.

Certainly, we can generate accurate deformations that we have seen because there is no spring back effect involved during laser forming. And we can achieve complex patterns as well. Some of the patterns I will show in the next slides and this is also improving the quality of the laser forming process or in general material forming process.

This is another very prominent advantage of the laser forming that reaching the unreachable areas, inaccessible areas. We can go to or we can access unreachable area where the mechanical tool are not possible to apply their mechanical energy or mechanical forces to get the particular deformation and that to generate the complex shape. It is not always possible to use the dies and punches to generate the complex shapes, lasers are helping to generate such parts.

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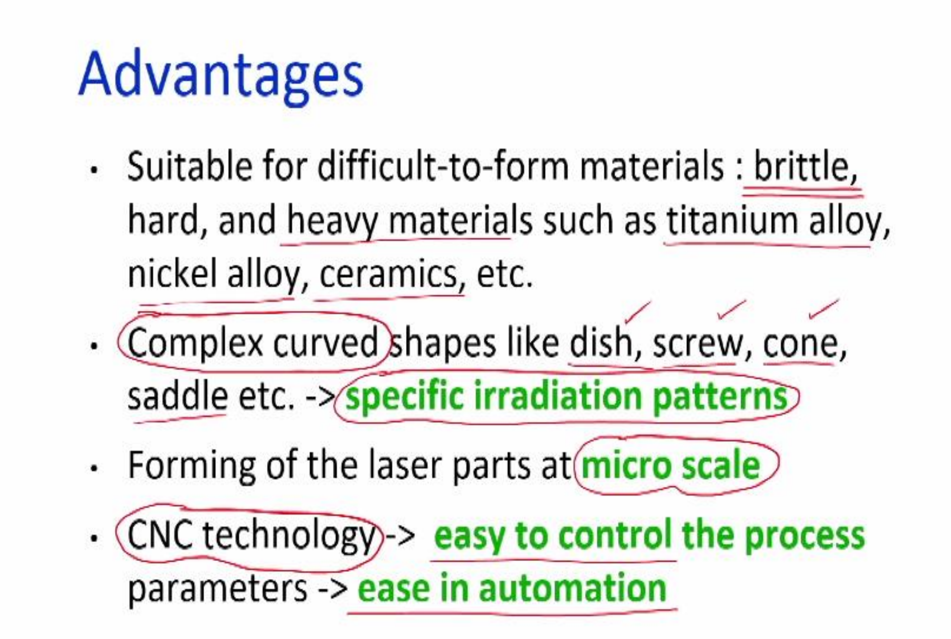

Lasers are very useful to deform brittle materials, difficult to form materials, heavy materials such as titanium alloy, nickel alloy even ceramics or the brittle material such as the magnesium.

In the coming lectures in next week when we will be discussing about the advance processes, advance application of the lasers we will see how lasers can be helpful to process the difficult to form materials such as magnesium.

Lasers are well capable of generating complex curve shapes such as dish, screw, cone and saddle. Of course, we have to design or we have to develop some sort of specific irradiation patterns to get this complex shapes, dish, screw and cone. This is another very important advantage, the micro scale forming. In mechanical based material forming it is very difficult to achieve precise 1.5 degrees. In lasers it is very much possible by application of controlled heating laser heating generation of 1 degree or 1.5 degrees during the laser micro scale forming operations.

With the use of CNC technology now lasers can be easily controlled and we can automate the laser-based processing by providing the required movements to the work part in x-y direction.

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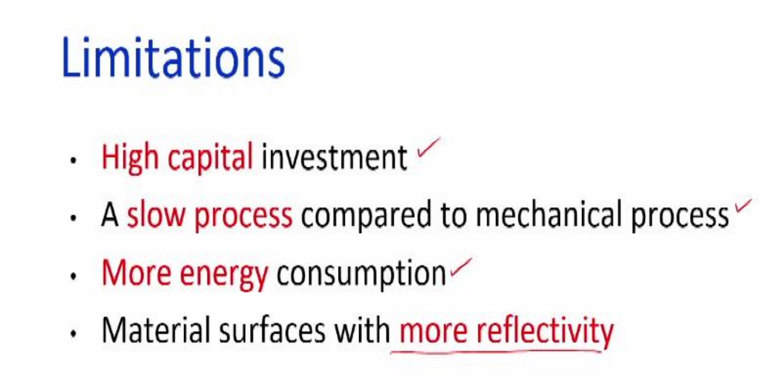

However, there are certain limitations associated with the laser forming. The first is high capital investment. It is quite obvious when we are using lasers the initial cost is little high in comparison with the conventional metal forming machine tools.

The process is comparatively slow. When we are talking about the special purpose automated mechanical based material forming, the laser forming process is slow, but it is useful for small batches.

More energy consumption that is quite obvious because the efficiency of most of the lasers is quite low, the energy consumption would be high. Therefore it is very much essential to apply the optimal level of process parameters. Lot of work is being carried out in this area, there are lot of research works being done by students in the academic as well as industrial laboratories to find out the optimal level of process parameters and use them to enhance the productivity in laser forming process.

This is another limitation, the work parts or the workpieces which are having the reflectivity, materials with more reflective surfaces are difficult to deform because there would be very less absorption of the photon energy, the material heating would be less and naturally we will not achieve the good quality bend angle.

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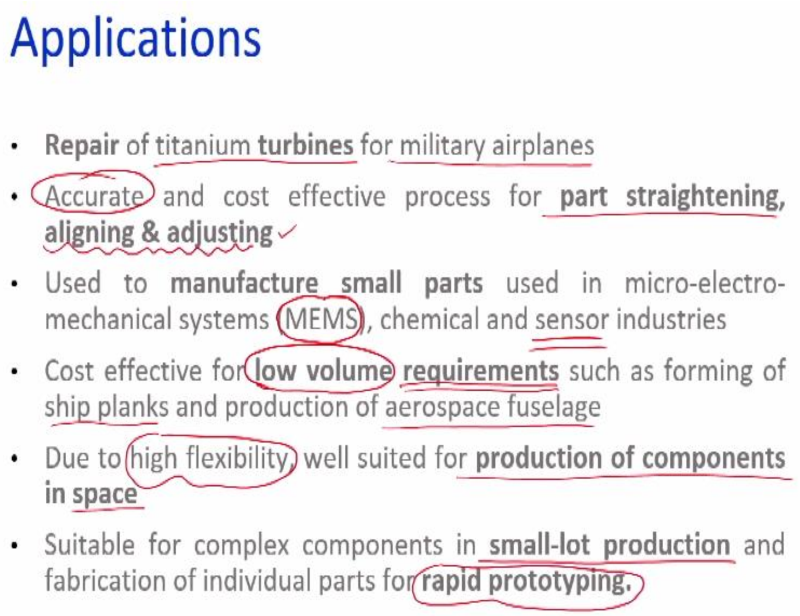

What are the various applications in the industry? The first application is repair of titanium turbine for the military airplanes. For the repair application where it is not possible to take the mechanical punch and die at the site of the work part, the turbine blades or turbine parts which are made up to high strength steel say titanium and we want to repair them, for such application lasers are very useful, you apply or you heat up the part in a controlled fashion and get it corrected.

For straightening of the part, accurate and cost effective straightening, this is another very useful application of the laser. Aligning and adjusting of the work parts. When there is error in manufacturing of the parts and at the time of assembly or at the time of welding two parts, it is noted that there is some sort of error in the assembly. The lasers are very useful in aligning and adjusting. When there is an error in the work part dimensions due to manufacturing defects or human errors there maybe problems in aligning or adjusting the parts. In these situations lasers can help us to have the controlled irradiation and by using the upsetting mechanism you can adjust the width and get it corrected.

As I mentioned in MEMS parts the micro electromechanical systems parts we need to get a very low bend angle and that to be very précise for connectors of various hardware parts in electronic devices.

In sensors as well when we want to have bending of the sensor parts with very high precision, then also lasers can be utilized.

For low volume requirements of the products. If we want to process the parts at a low volume in small batches lasers are very useful and these are the parts say the ship planks or the aerospace fuselages.

As we know that the lasers are having high flexibility, that is why they are very much useful in space applications in the space stations due to the flexibility of application of the lasers they are very much useful and in space there is no gravity in that case the lasers are finding very good applications in no gravity zones where we cannot use the mechanical loading which required the gravity.

Lasers are very much required or they are finding application in small lot production that is why they are quite popular in rapid prototyping. We want to develop the prototypes in a rapid way in the early stages of the product development at the initial level of the product development, at the conceptualization level of the product development, that time the lasers are very much useful to get the realization of the product, how it will look like what would be its shape and size and whether it is as per the design or not.

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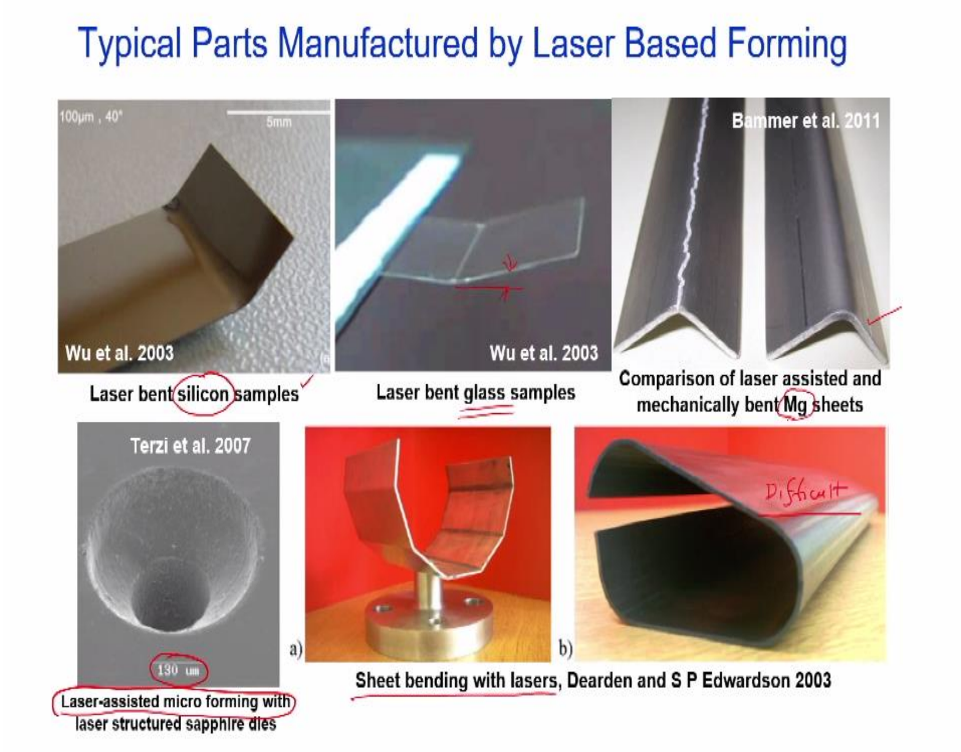

Some of the laser bend specimen can be seen on your screen. You can notice that this is the specimen of silicon. Silicon samples were successfully bent by using lasers. Here, you can see even the glass, the glass is transparent material and very brittle that was also processed by using laser and successfully there was a bending of the glass material.

Moreover, the magnesium sheets also are bent by using lasers. We will be having a detail session on laser assisted forming of the magnesium sheets in the next weeks.

Then laser assisted micro forming, this is an interesting thing when we want to manufacture very small size features we are using lasers for preheating to reduce the flow stresses and to generate the precision complex features on the work parts. Here also you can see the sheet bending by using lasers and a complex shape part has been generated. This is also very difficult part that to be generated or manufactured by using mechanical bending. All these are the capabilities of the laser based forming operations.

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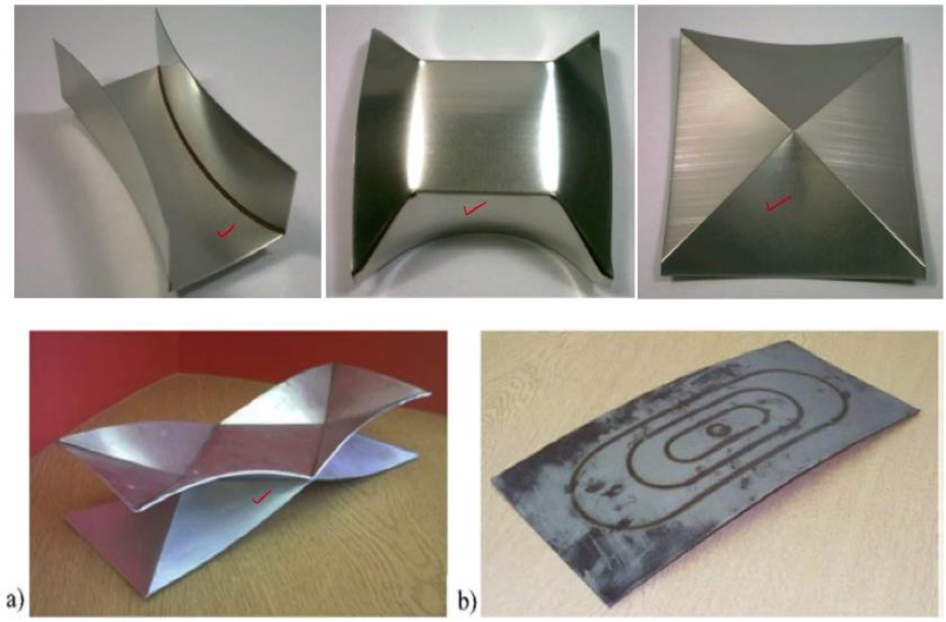

Shapes generated by laser forming (Dearden et al. 2003, Dearden and S P Edwardson 2003)

Few more designs or few more work parts of complex shapes are there on your screen. You can notice here the saddle shaped work parts or the dome-shaped work parts or complex shapes which are there on your screen. In some cases these are difficult or in some cases not possible by using the mechanical based forming operation, but by applying the specific laser irradiation patterns and by applying the optimal levels of laser beam parameters these parts can easily be generated by using laser based forming.

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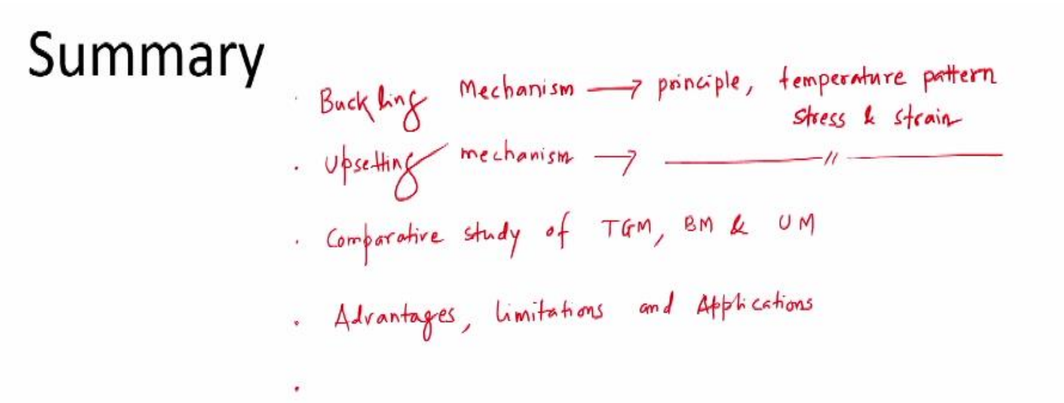

Fine with this I would like to summarize this lecture. In this lecture, we have seen the buckling mechanism. In buckling mechanism, we have seen the principle, the temperature pattern, stress and strain pattern. Similarly, we have also seen the upsetting mechanism and the same parameters also we have noted or we have studied

After that the comparative analysis of (comparative study) of TGM, BM and the upsetting mechanism. Then we have seen the advantages of laser based forming, limitations and its applications and at the end we have seen some of the complex shapes which are generated by using laser based forming.

With this I would like to stop for this lecture that is the Lecture 2 of Week 4 Laser Based Manufacturing. In the next lecture, we will be studying various process parameters involved in laser-based forming and how these laser parameters are affecting the laser performance.

Till then good bye. Thank you for watching this lecture. Namaste.