Advanced Manufacturing Processes
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Module - 3
Advanced Machining Processes
Lecture - 13
Equipment and Process Parameters in LBM

Welcome to this second session on laser beam machining under the course advance manufacturing processes. In the previous session, we have discussed about the basic features of laser and laser beam machining, how to produce laser, different lasing materials and their characteristics. Moving ahead, we will now discuss about the equipment, the process parameters involved in laser beam machining process and advancement in the laser beam machining.

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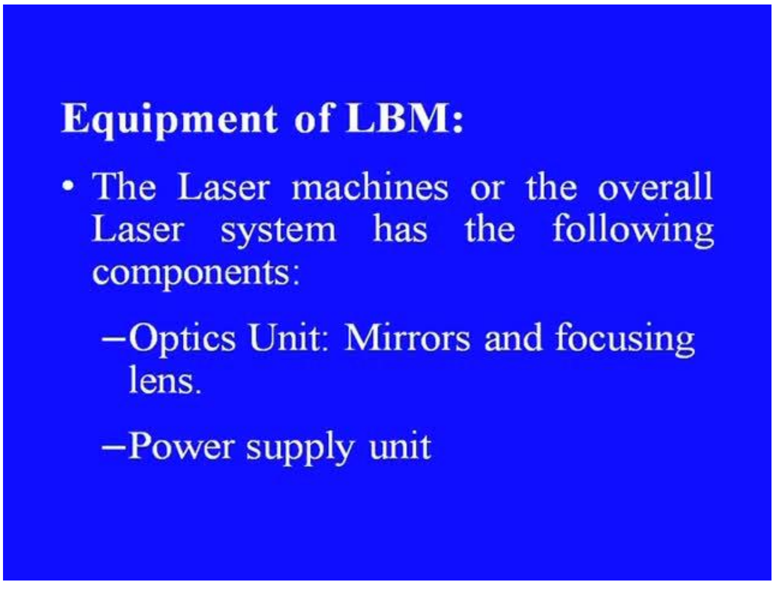

Let us first look at the equipment of this laser beam machining. Laser machines or the overall laser system has the following components, major components. One is optics unit, that consists of mirrors and focusing lenses, another is the power supply unit. Then another important subsystem is the work-piece rest table, which maybe fixed or may move in up to two directions x and y. This can be computer numerical controlled system. Then scrap removal system, then assist gas gas system or debris removal system and then the control unit.

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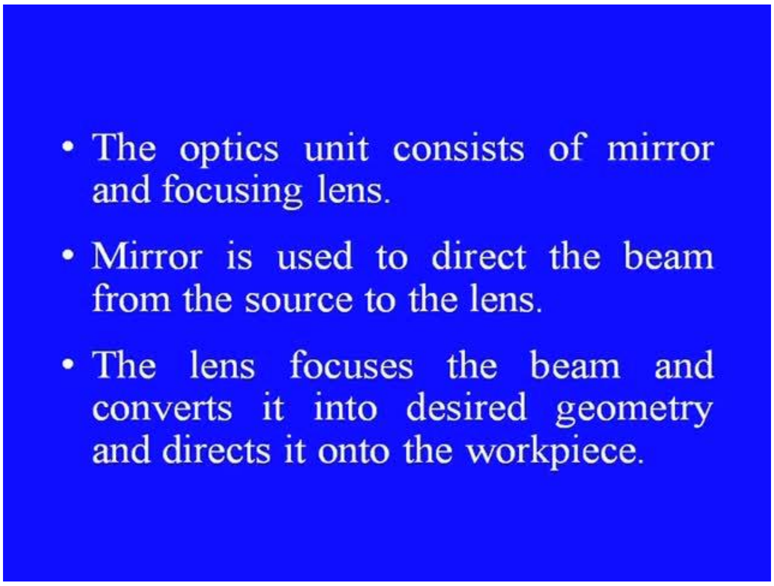

The most important unit the optics unit consists of mirror and focusing lenses. As we have discussed earlier also, this mirror plays a very vital role in production of lasers, their amplification and providing the output of the system. The partially reflecting mirrors will provide the outputs in the form of the amount of energy we required, as per the system requirements or the applications requirement. The focusing lenses will be responsible for focusing the laser into the work spot where we want to do the machining or welding or engraving etcetera.

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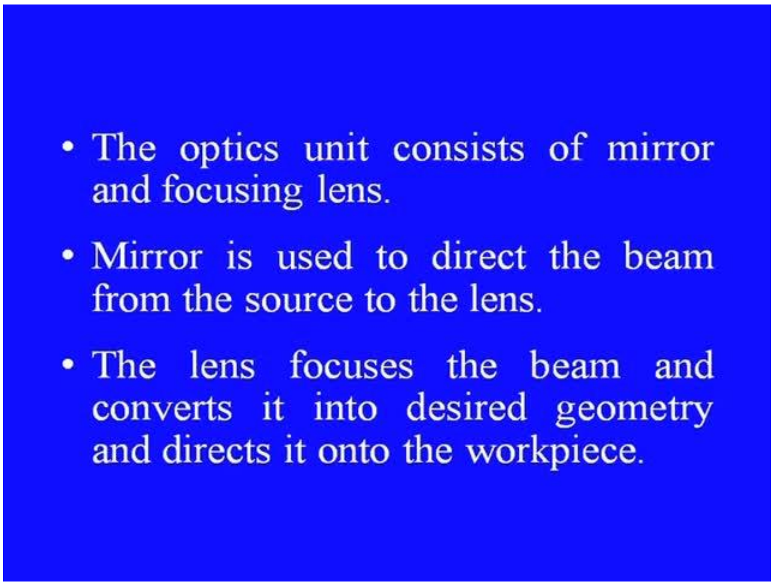

The mirror is used to direct beam from the source to the lens. The lens focuses the beam and converts it into desired geometry and directs it on to the work-piece. The assist gas system removes the molten metal, which does not get vaporized at the end. As we have already spoken, this laser works on the basically the removal of material on the thermal principle. That is it melts the material and vaporizes the material and thereby the material from the work-piece gets removed.

Now, in this process some amount of material, which may get melted, but may not get completely vaporized, may get stacked to the work-piece itself, which may create problem later on or it might stick to the work-piece in the form of small buds. Therefore, it is needed that these small materials melted materials, but not vaporized completely to be removed during the process itself, when they are soft enough. Therefore, we take help of one assist gas, which will ultimately blow away these melted materials from the machining spot.

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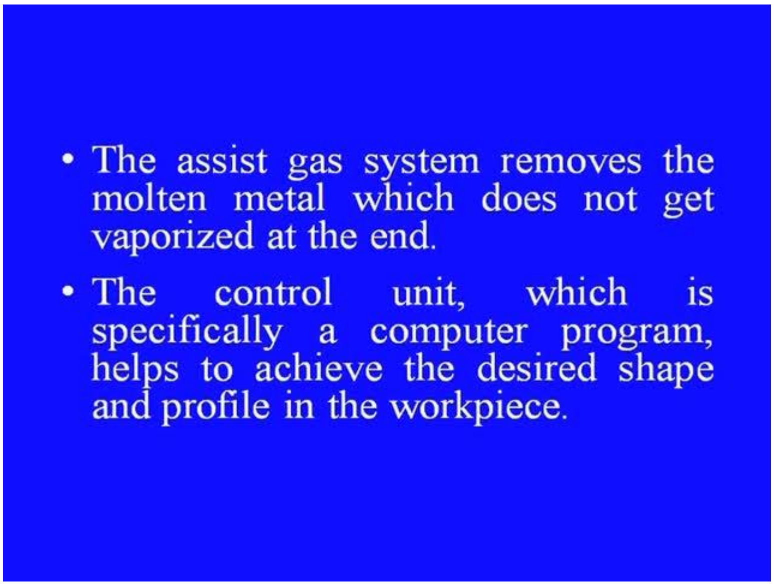

The control unit, which is specifically a computer program helps to achieve the desired shape and profile in the work-piece. Now, let us see the process parameters in laser beam machining. The process parameters in laser beam machining can be grouped in the following categories.

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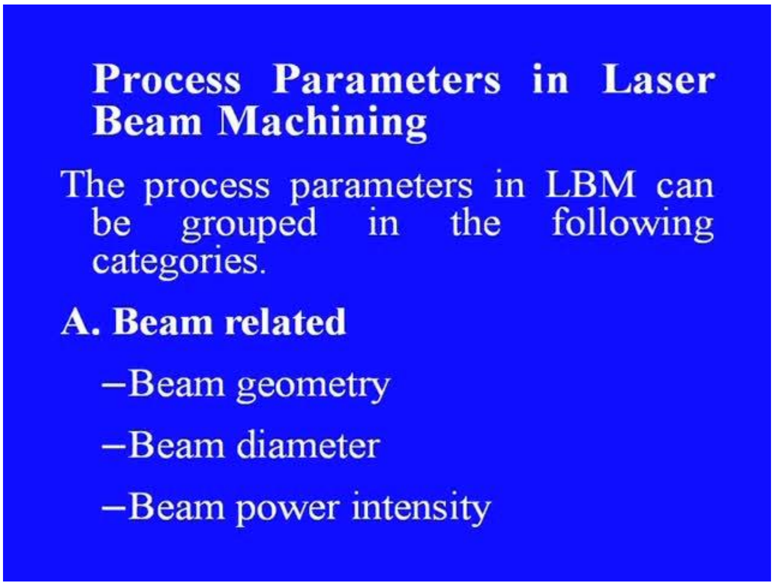

A beam related parameters, this include beam geometry, beam diameter, beam power intensity. This beam diameter and beam power intensity, they play very vital role in the sense that beam diameter will define, how fine we will be able to cut on the work-piece. And beam power intensity will dictate, how intensely we can apply the laser power on the work-piece, and how deep we can go with that power intensity, and how fast we can cut.

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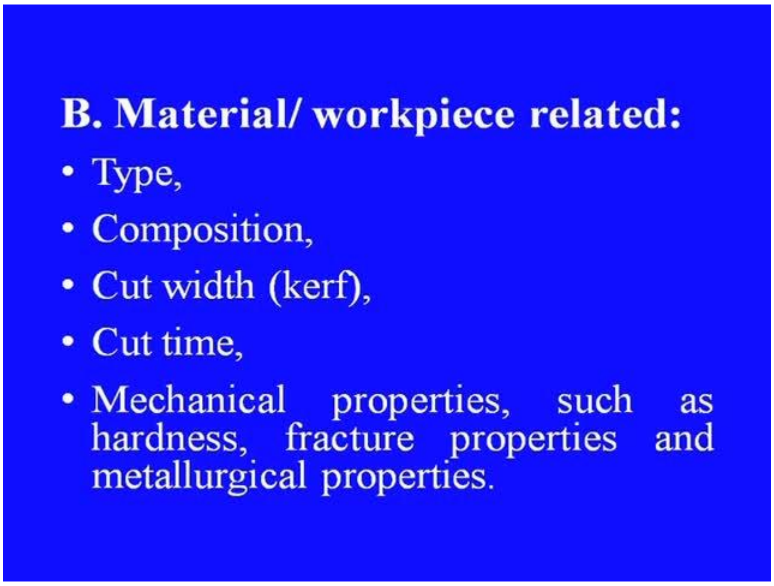

The next group of parameters are work-piece or material related. They consist of the type of the material, composition of the material, cut width, which in terms of laser beam machining terminology also called as kerf. Then cut time, then mechanical properties such as hardness, fracture properties and metallurgical properties of the work material. The four physical parameters of the work-piece significant to laser beam machining includes, reflectivity, specific heat, thermal conductivity and latent heat. Reflectivity is important in the sense, higher the reflectivity of the work-piece material, lower will be the efficiency of laser machining, because most of the laser energy will be reflected back by the work-piece, instead of getting absorbed and getting work done. This is something like this.

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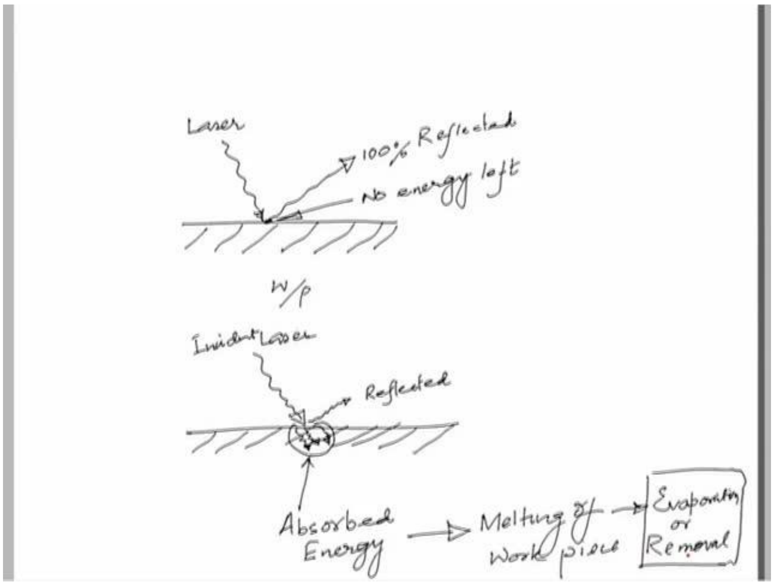

Say for example, this is the work-piece and this is the laser. If this laser is again reflected back say 100 percent reflected, then there will be no energy left here, no energy left here for doing the work, no energy left. However, if the material on the other hand absorbs some energy, say this is laser, this is incident laser, we can call then some amount of energy is absorbed here and maybe we or a few percentage of energy is reflected, this is reflected then this absorbed absorbed energy here, this is to some extent, so this is we call the absorbed energy. So, this will be responsible for, this will do the melting of the work-piece and finally, we will get evaporation. Evaporation or this is also called removal, so our ultimate goal will be to evaporate the material or removal of the material.

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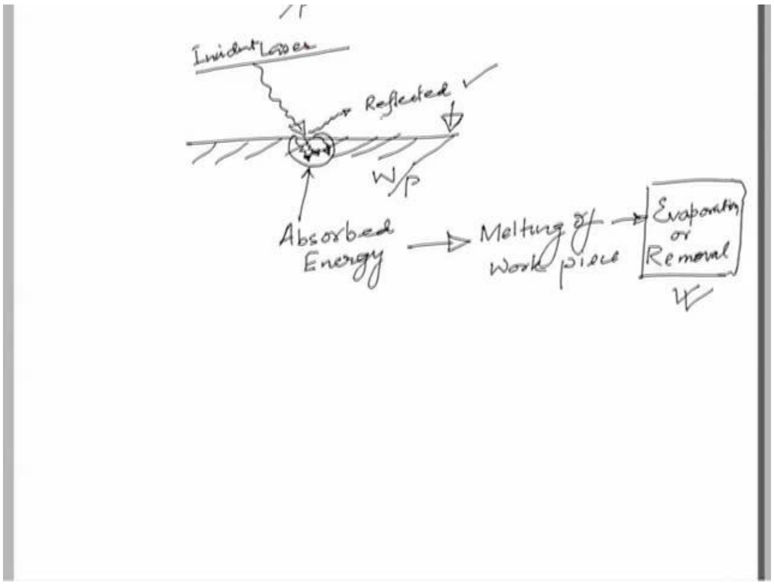

Hence this absorption of the energy by this work-piece material is very, very important rather than getting reflected. So, this would be as less as possible in case of any work-piece that is to be worked with laser energy. The four physical parameters preferred to be lower in magnitude for increasing the process efficiency, as the energy required to melt and vaporize the material is lesser in l b m, this we have already discussed.

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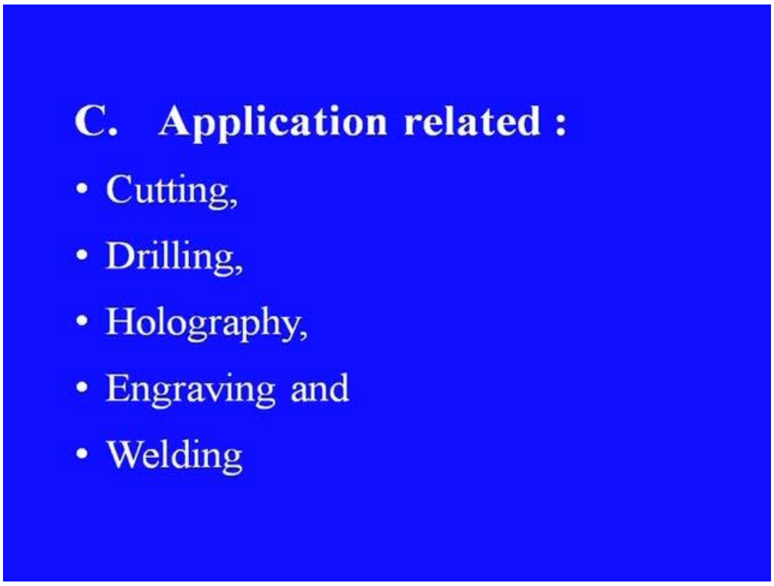

Then the third category of parameters are application related, these include whether we are applying it for cutting, drilling, holography, engraving or welding. These processes or these applications of laser, demands different kind of settings of laser like for cutting whatever the energy intensity is required, will be different from that of required in holography. Similarly, energy required or intensity laser intensity required for engraving, will be much different from that of welding. Thus the application also becomes very, very important while deciding the parameters or the settings of the laser.

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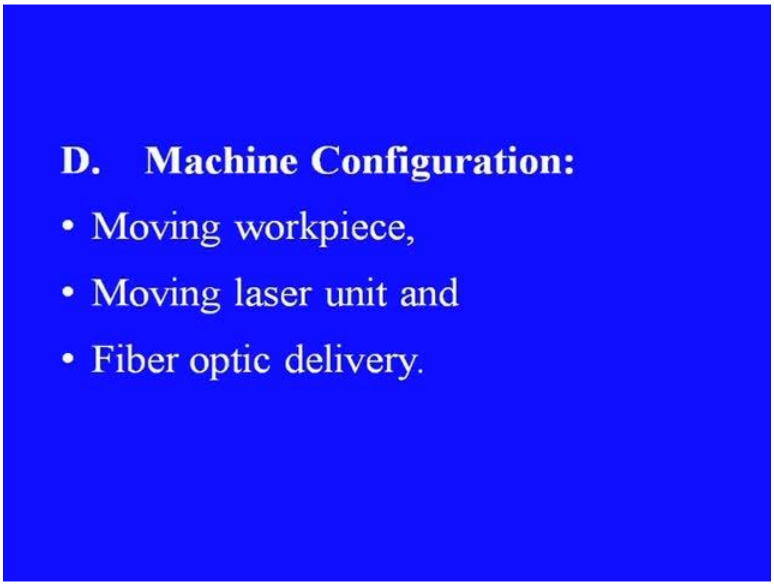

The fourth category of parameters are related to machine configuration. These include whether the work-piece is moving or not, then the moving laser unit and then fiber optic delivery.

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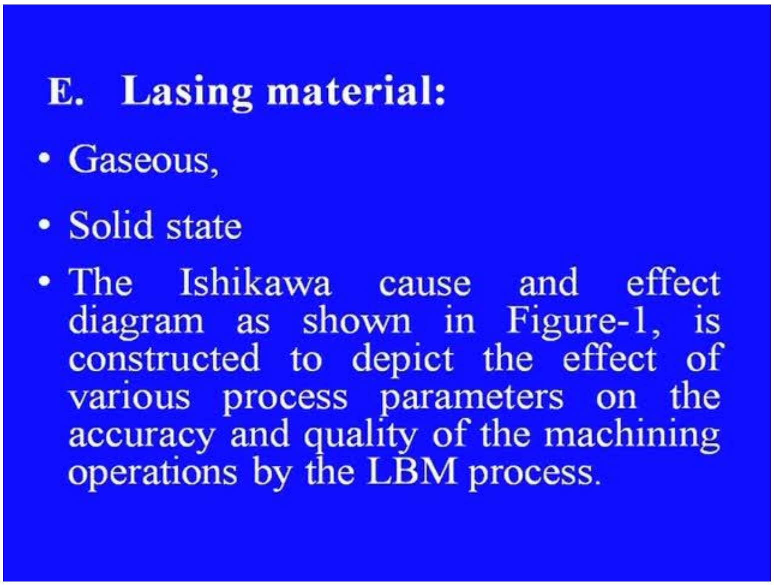

The fifth group of parameters are related to lasing material, whether the material is gaseous, whether the material is of solid state etcetera. As we have already discussed carbon dioxide is one of the most important gaseous materials, lasing materials, widely used in the industries. Then ruby and neodymium atrium aluminum garnet are two solid state materials, used very widely for lasing purposes. The Ishikawa cause and effect diagram is shown in the following figure, to depict the affect of various process parameters on the accuracy and quality of the machining operations.

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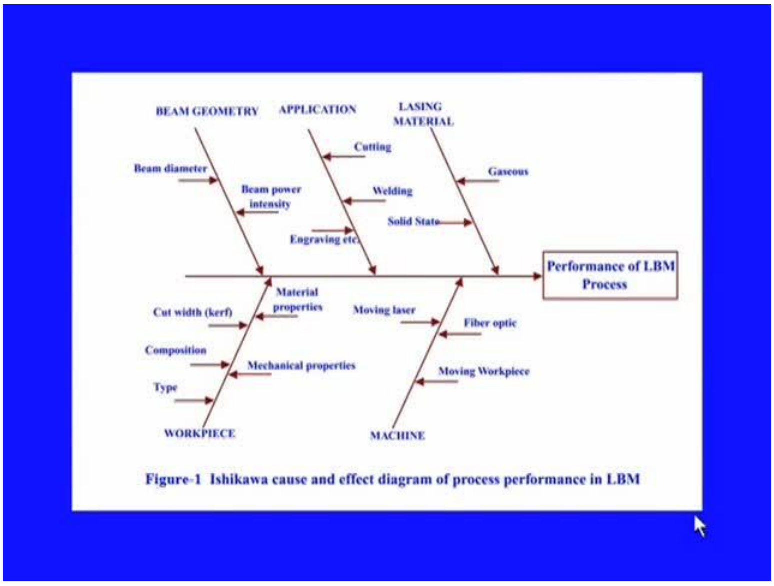

Figure-1 Ishikawa cause and effect diagram of process performance in LBM

So, this is the Ishikawa diagram in which these parameters are shown like this. Beam geometry, which includes beam diameter and beam power intensity. Then application oriented, as we have already discussed that is whether it is cutting, welding or engraving etcetera, then as far as the lasing material is concerned, whether they are gaseous or the solid state. Then as far as the work-piece is concerned, we have already discussed type of work-piece, composition of work-piece, the kerf width, then mechanical properties and then material properties etcetera.

Then also the machine related parameters like, whether the work-piece is moving, whether the laser lasing unit is moving or how it is being delivered, the laser is delivered, that is through fiber optic or so. All these parameters influence the performance of the laser beam machining process. Now, let us see another issue very important issue as far as the laser is concerned, that is safety issues. Lasers can burn and make a person blind, this is very, very serious issue, as far as the operator is concerned. Hence eyes and skin should be protected from the scattered beams. The low power lasers can also cause damage to the retina leading to blindness.

Therefore, one has to be very, very careful. Operator should wear gas mask to protect against the generated fumes. In many a cases it has been seen, while working with laser as the material get heats up or material starts evaporating, this causes some gases to evolve, these gases may be harmful at times for the operator or for that matter the entire environment or the surroundings. Therefore, at least the operator should wear protective masks to get rid of such harmful fumes etcetera or the toxic gases etcetera and there should be proper ventilation or gas extraction systems in the laser unit.

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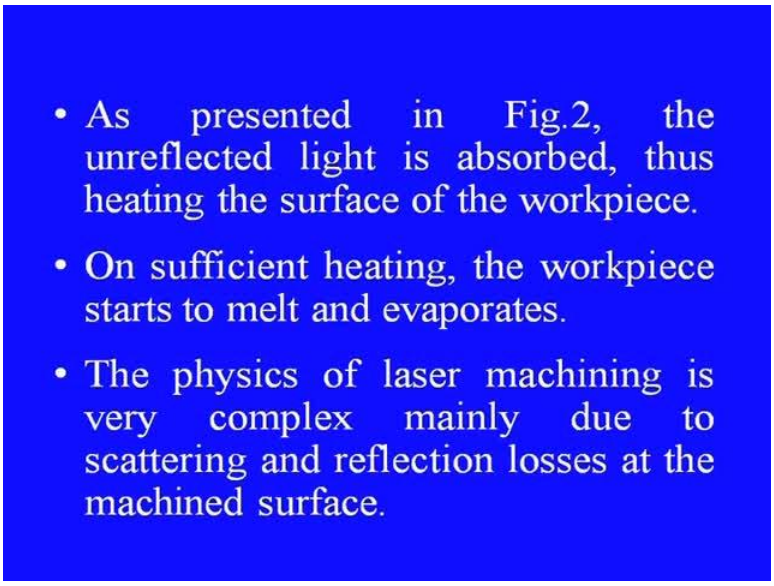

As presented in the next figure, the un reflected light is absorbed by the material, thus heating of the surface work-piece surface takes place on sufficient heating. The work-piece starts to melt and evaporate the physics of laser machining is very complex, mainly due to the scattering and reflection losses at the machined surface.

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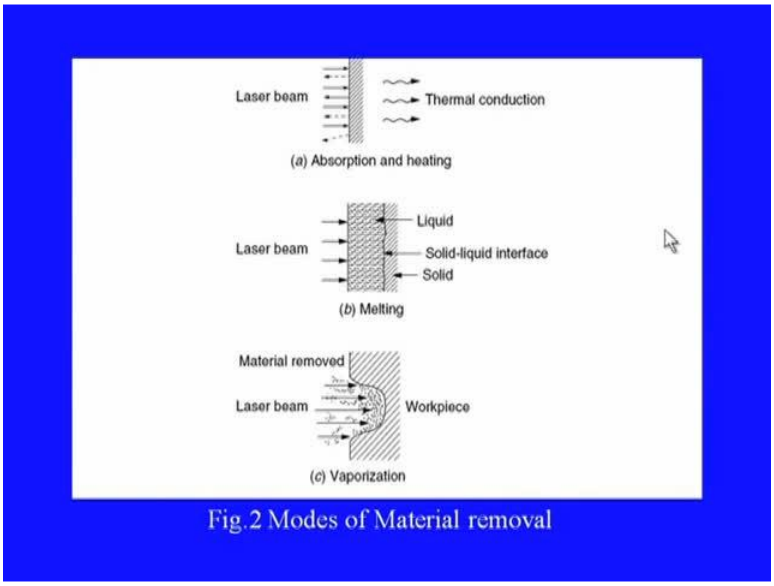

Fig.2 Modes of Material removal

So, this is being shown in this particular figure. This is the laser beam, this is the work-piece surface, then some of the beams as I told already, some of the laser incident beam will get reflected from this surface and some will get absorbed by this material, which will cause the material to get heated up and this heated because of this layer gets heated up, the heat will be conducted away inside the material by normal classical ways of heat conduction. On continued application of laser beam, if we continue to do so for some time, then the heated material starts melting.

This will become like semi molten or the molten or the liquid state, instead of the solid, as we have seen in the first case. This will get progressively transferred or the width of the molten zone will get increased, as we keep on pumping laser energy on to the surface. On continued application of laser beam, some of the materials molten materials as we have seen here, will get evaporated and they will come out from this surface causing dent here. We can say the material is getting machined, in terms of machining terminology and in this way with continued application of laser beam, this material removal will keep on taking place, and we will be finally getting an effective hole on to the work-piece.

This is because of the vaporization of the material additionally heat diffusion on to the bulk material, causes phase, change melting and or vaporization. Depending on the power density, time of beam interaction the mechanism progresses from one of the heat absorption and conduction to one of melting, and then vaporization machining by laser occurs, when the power density of the beam is greater than what is lost by conduction convection and radiation.

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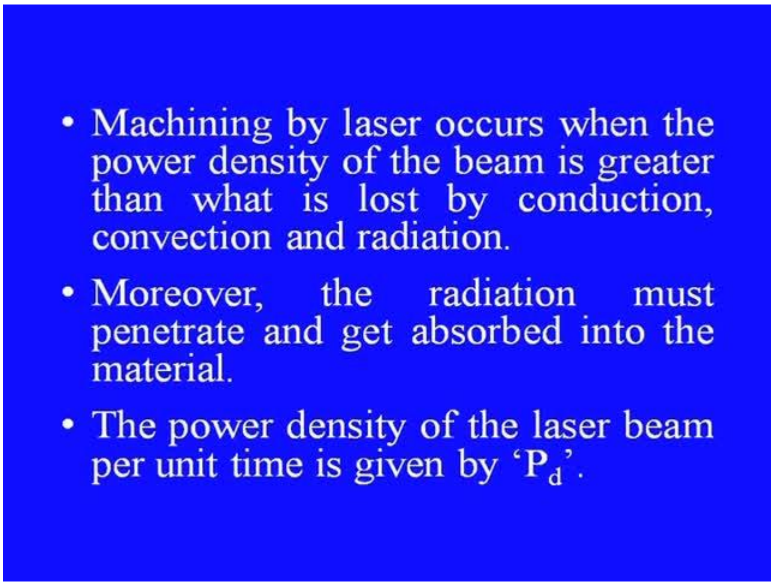

Moreover, the radiation must penetrate and get absorbed into the material. The power density of the laser beam per unit time is given by P d.

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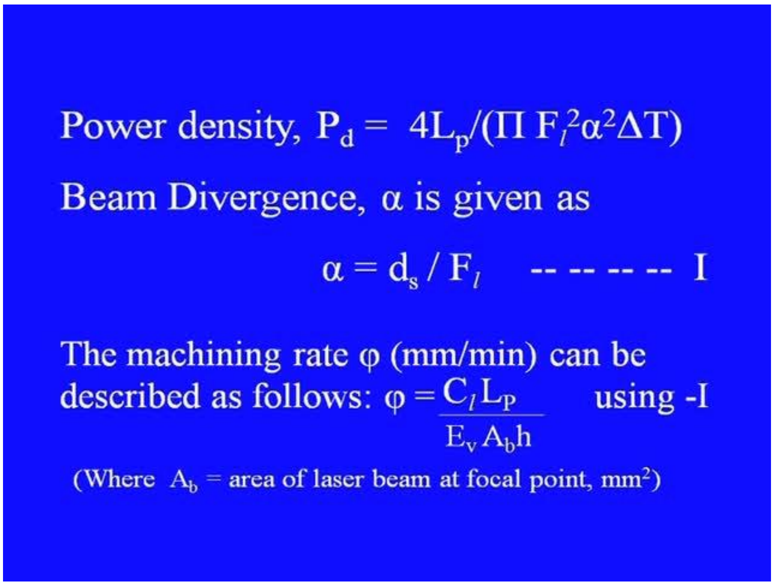

This P d is defined as 4 times L p divided by pi F l square, alpha square into del T, where as beam divergence alpha is defined as d s by F l. On the other hand the machining rate in millimeter per minute can be described as follows, like machining rate F i is given by C l by into L p divided by E v into A b into h, where A b is the area of laser beam at the focal point expressed in millimeter square.

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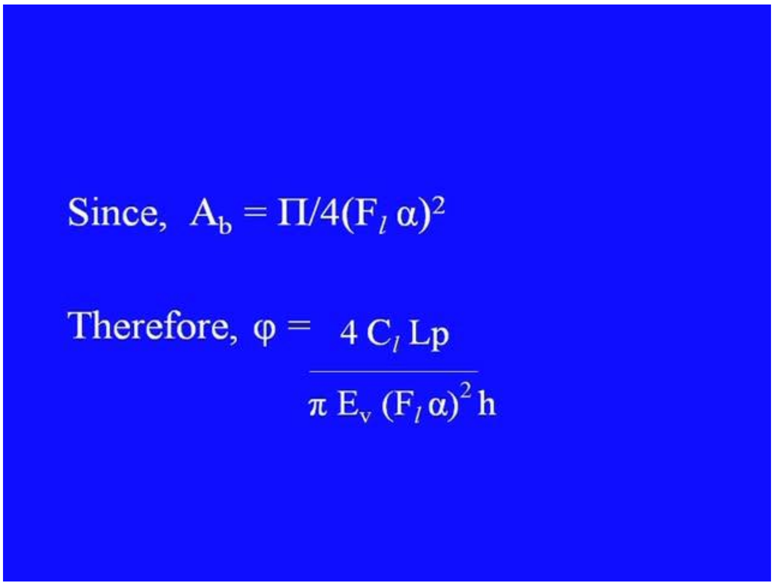

On the other hand A b is described by pi by 4 F l into alpha whole squared. Therefore finally, we get the material removal fi as 4 C l into L p divided by pi E v into F l into alpha squared into h.

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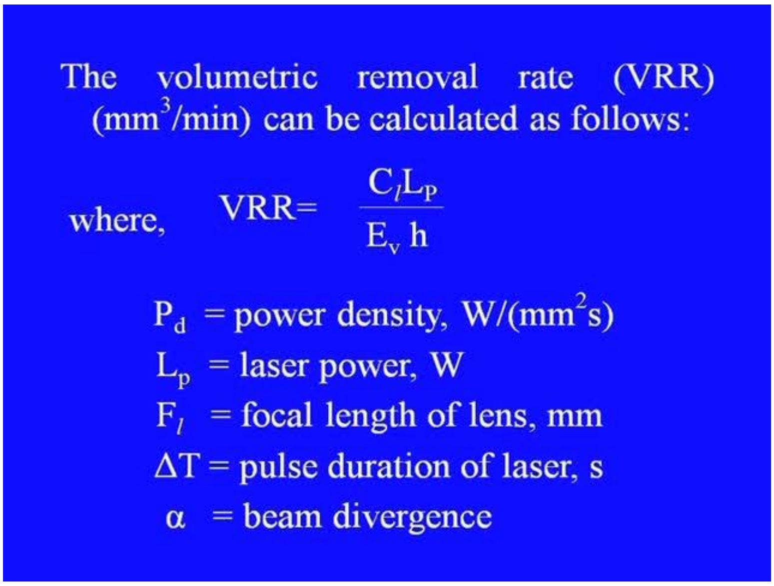

The volumetric removal rate also called VRR in millimeter cube per minute can be calculated as C l into L p divided by E v in to h, where P d is the power density, which is expressed in watt per millimeter square second. Then L p is the laser power in watt, F l is the focal length of the lens that is in millimeter. Del T is the pulse duration of laser that is expressed in second and alpha as we have already defined is the beam divergence. C l is the constant, depending on the material work material and conversion efficiency, that is expressed in millimeter per minute.

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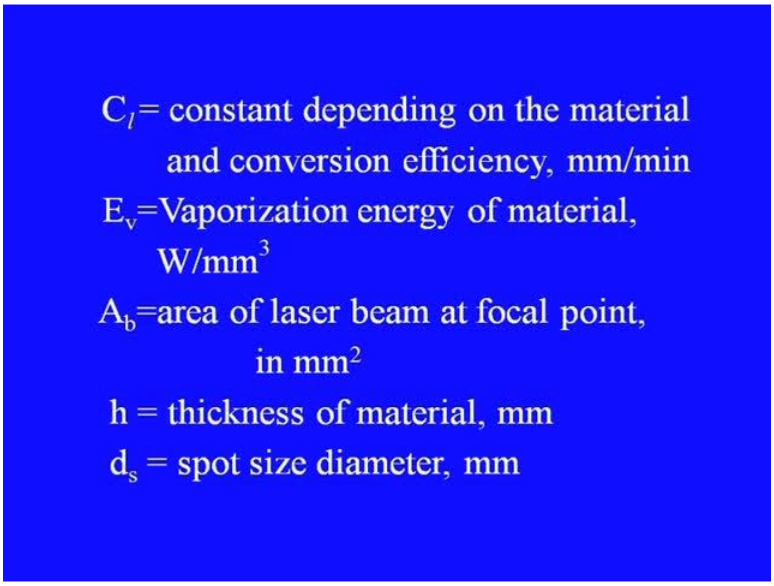

E v is the vaporization energy of the material expressed in watt per millimeter cube. Then A b is the area of laser beam at focal point expressed in millimeter square. h is the thickness of the material in millimeter and d s is the spot size diameter, expressed in millimeter. The following figure presents, a schematic diagram of laser drilling and phase changes. The factors can be related to laser beam machining drilling process and are discussed like this, in which pulse energy is one of the important factors. It is recommended that, the required peak power should be obtained by increasing the pulse energy, while keeping the pulse duration constant.

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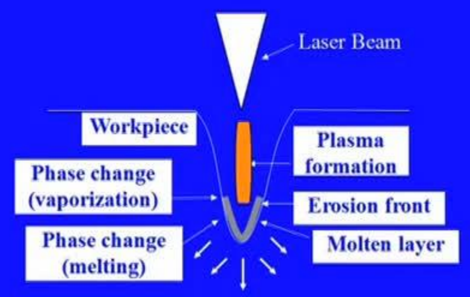

Fig.3 Laser drilling and phase changes

This is the schematic of laser drilling process in which, this is the laser beam incident on the work-piece. This is beam focused by the focal optic system lens system and the other optic system, which are not been shown here, only the focused laser beam is being shown. In between there will be a plasma formation and then that will, this heat of plasma will cause the material to melt and erode in fact evaporated, which will cause the erosion of the material and it gets machined. So, this causes the phase changes; that is from solid to molten, then molten to vapor state.

So, here three changes are there. From solid it gets melted, then the molted material again gets vaporized and these vapors comes out of this material leaving behind some spots, which will be considered as the machined spot. So, this is being shown like this and at the same time as we proceed machining this material in the subsequent layers in the work-piece, gets melted or gets heated up first and starts melting subsequently and gets evaporated. Another important component in the laser beam machining, as we have already indicated is the assist gases.

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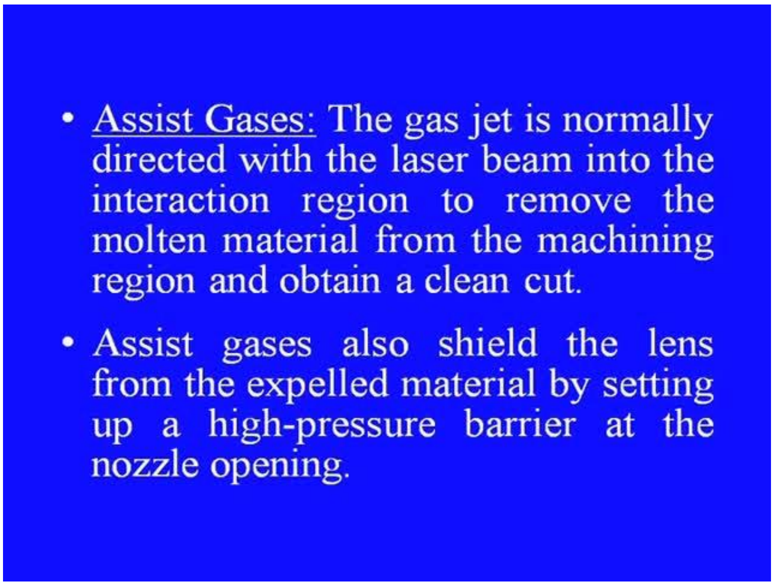

The gas jet is normally directed with the laser beam into the interaction region to remove the molten material from the machining region and obtain a clean cut. The assist gases also shield the lens from the expelled material by setting up a high pressure barrier at the nozzle opening. This is another important function of the assist gas system, for usually this lens systems used in the laser focusing are of very high quality and costly. Therefore, it is to be assured that this lens system do not get affected very easily by the evaporated work material. Therefore, it is needed that these evaporated materials to be sent away as far as possible from the lens system and once we use this assist gas system, then they do this function as well.

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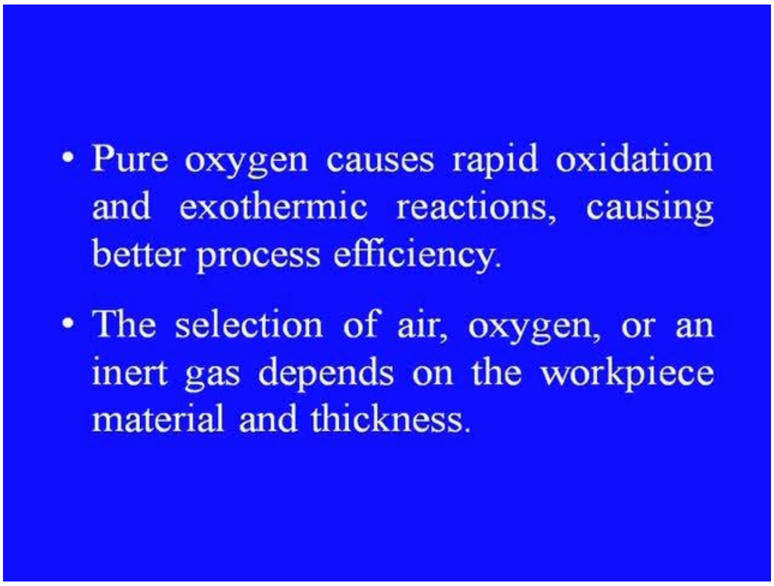

Pure oxygen causes rapid oxidation and exothermic reactions causing better process efficiency. The selection of air oxygen or an inert gas depends on the work-piece material and thickness. Now, let us come to the material properties and environment. These include surface characteristics such as reflectivity and absorption coefficient of the bulk material, additionally thermal conductivity and diffusivity density specific heat and latent heat are also considered. The following table shows the laser applications and type of lasers used in different work situation.

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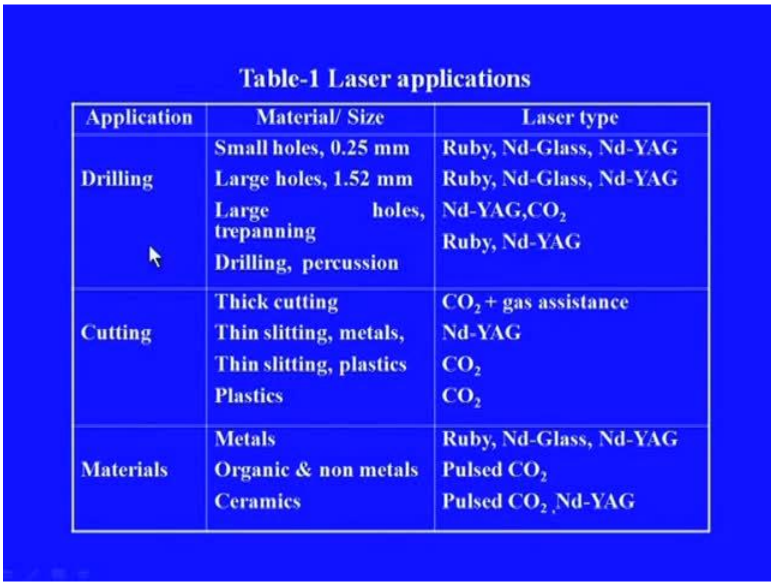

Table-1 Laser applications

Application	Material/ Size	Laser type
Drilling	Small holes, 0.25 mm	Ruby, Nd-Glass, Nd-YAG
	Large holes, 1.52 mm	Ruby, Nd-Glass, Nd-YAG
	Large holes, trepanning	Nd-YAG, CO_2
	Drilling, percussion	Ruby, Nd-YAG
Cutting	Thick cutting	CO_2 + gas assistance
	Thin slitting, metals,	Nd-YAG
	Thin slitting, plastics	CO_2
	Plastics	CO_2
Materials	Metals	Ruby, Nd-Glass, Nd-YAG
	Organic & non metals	Pulsed CO_2
	Ceramics	Pulsed CO_2, Nd-YAG

In drilling, application drilling depending on different sizes say for small holes, that is diameter average diameter is 0.25 millimeter or so. Generally ruby laser or neodymium glass laser or neodymium yttrium aluminum garnet, also in short it is called Nd YAG are used. Similarly, for large hole drilling say diameter ranging up to 1.5, 2 millimeter or so or with trepanning then percussions, generally Nd YAG or ruby lasers are used. For large holes of course, carbon dioxides are are also used, as we have seen in the last session itself.

Carbon dioxide lasers are capable of giving very high output energy and therefore, they will be more effective as far as the large hole drilling is concerned. Similarly, for cutting of materials like thick cutting carbon dioxide with gas assistance is generally recommended because as we have already told, carbon dioxide gas we can have a high powered laser and cutting needs higher power. For thin slitting of materials etcetera where the energy requirement may not be as high as in cutting of thick plates etcetera even Nd YAG lasers can be used.

Then, for materials like for metals as far as the materials work materials are concerned for metals, generally ruby Nd YAG and and neodymium glass lasers are recommended. Then organic and non metals pulsed carbon dioxide lasers are recommended. Then for working with ceramics pulsed carbon dioxide and neodymium yttrium aluminum garnet is recommended. Let us see few developments, new developments in this laser beam machining process.

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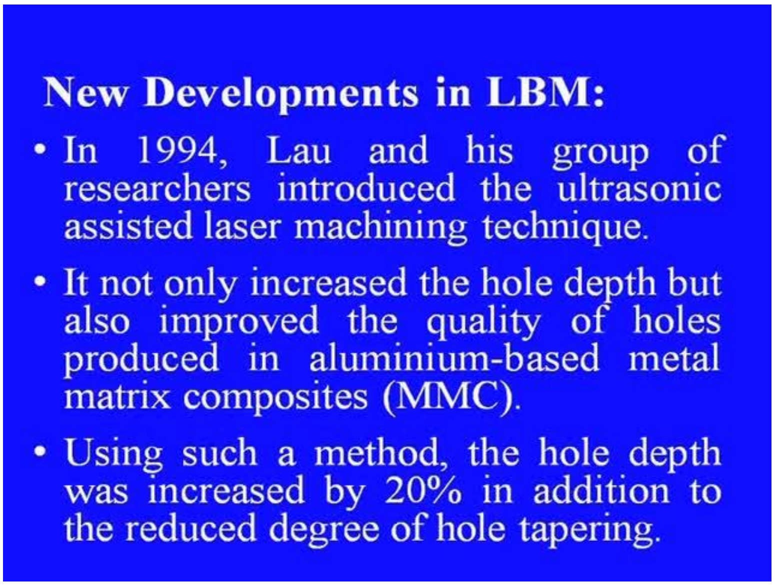

In the year 1994 Lau and his group of researchers, introduced the ultrasonic assisted laser machining technique. This process not only increased the hole depth, but also improved the quality of holes produced in aluminum based metal matrix composites. That is also called MMCs. Using such a method the hole depth was increased by 20 percent, in addition to the reduced degree of hole tapering.

This is another important aspect, as we have discussed in the last session itself, in laser beam machining we get usually to some extent the tapering, in while drilling holes. This tapering is nothing but a source of inaccuracy and better we can avoid this or minimize this, better we will get the accuracy or the precision in machining. This new development could overcome this to a certain extent.

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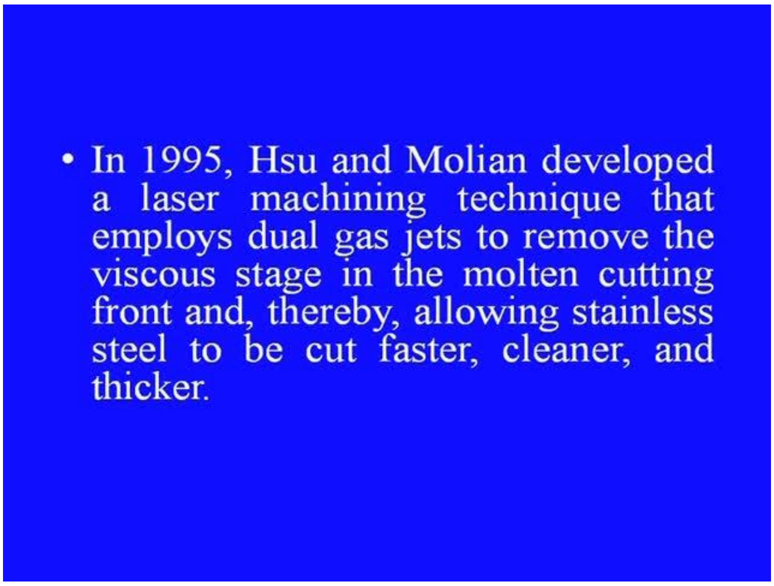

In the year 1995, Hsu and Molian developed a laser machining technique, that employs dual gas jets to remove the viscous stage in the molten cutting front and thereby allowing stainless steel to be cut faster, cleaner and thicker. So, this is another development from the basic laser machining in which, dual gas jets are being used and that improved the performance of the system.

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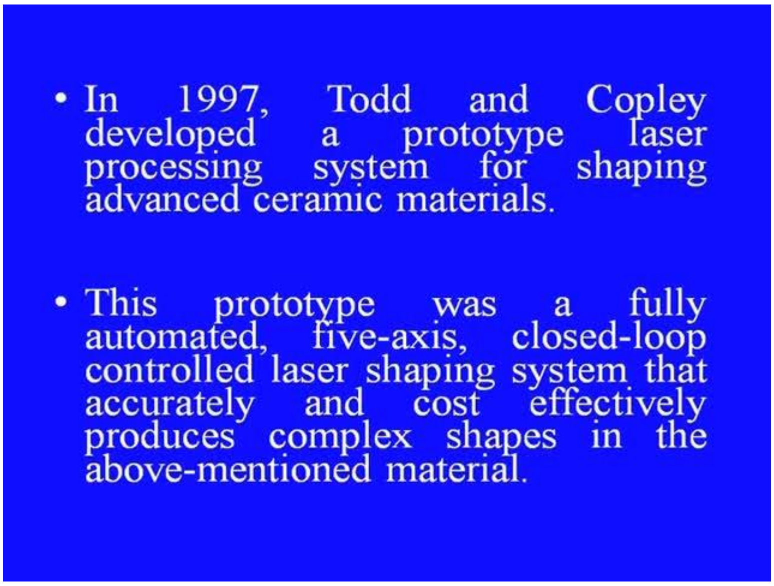

In the year 1997 Todd and Copley developed a prototype laser processing system for shaping advanced ceramic materials. The prototype was a fully automated system having five axis, closed loop controlled laser shaping system which could accurately machine and it could cost effectively produce the complex shapes in the ceramic materials. As we know, ceramic materials are usually difficult to machine in the conventional processing methods, but they are good candidates to be processed by using non conventional machining methods, one of which is laser beam machining. Then another development was laser assisted electric discharge machining process.

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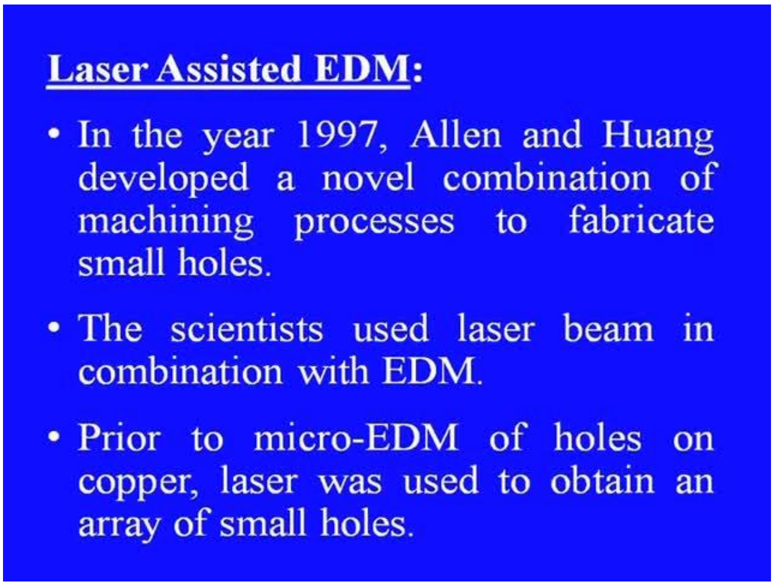

In the year 1997 itself Allen and Huang, they have developed a novel combination of machining processes to fabricate small holes. The scientists used laser beam in combination with EDM, conventional EDM. Already details regarding this EDM process, working, principles, the machines different components, we have discussed in one of the previous sessions. Prior to micro EDM of holes on copper, they used laser to obtain an arrayof small holes the holes, were then finished by micro EDM. This method had showed that the machining speed of micro EDM was increased an electrode tool wear was significantly reduced, while the surface quality remained unchanged. Thus this is considered to be a significant development in this area of laser beam machining.

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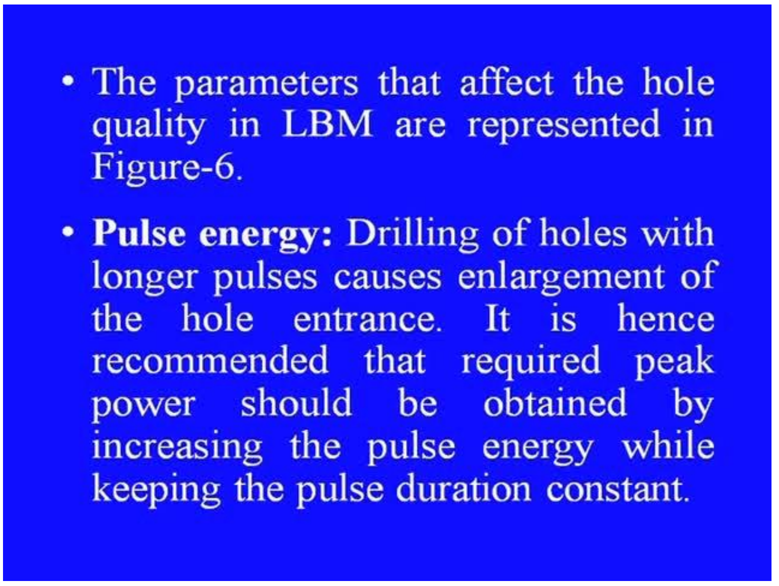

The parameters that affect the hole quality in laser beam machining are represented in the following figure, in which pulse energy is one of the important parameters in drilling holes with longer pulses causes enlargement of the hole entrance. It is hence recommended that required peak power should be obtained by increasing the pulse energy, while keeping the pulse duration constant this is schematically shown here.

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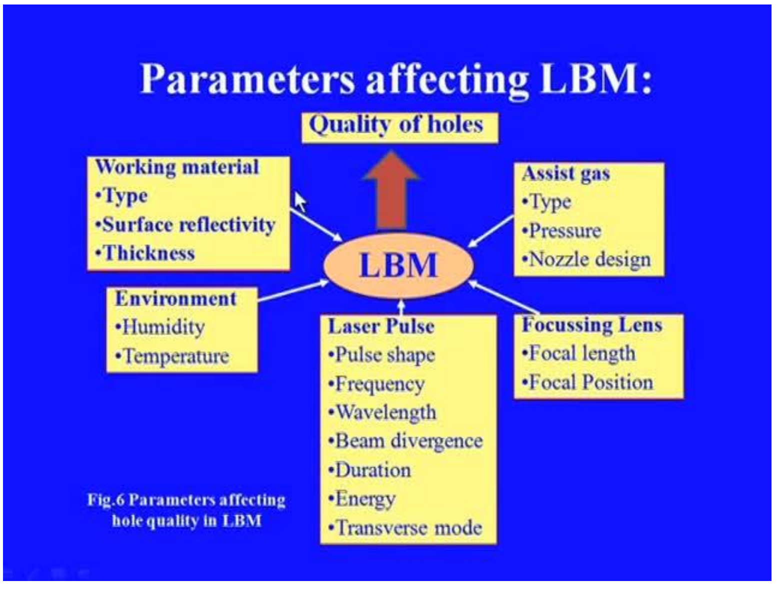

The quality of holes depends on different parameters, that is work material parameters like type surface reflectivity the thickness of the work material etcetera. Then the environment, then the nozzle design for this, then as we have already discussed the focusing lens system is a very vital system. As far as the laser beam machining is concerned and the quality of these drilled holes will depend mainly on this focusing lens system. The focal length and the focal position and to some extent the taper formation will depend on this.

Then the laser pulse, this is one of the major factors that affects this quality of holes. So, this include the pulse shape, then the frequency wavelength beam divergence, then beam duration, beam energy and the transverse mode. Let us see the effect of pulse duration on this hole drilling. The range of pulse duration suitable for hole drilling is found to be 0.1 to 2.5 milliseconds. High pulse energy that is around 20 joules and short pulse duration are found suitable for deep hole drilling in aerospace materials.

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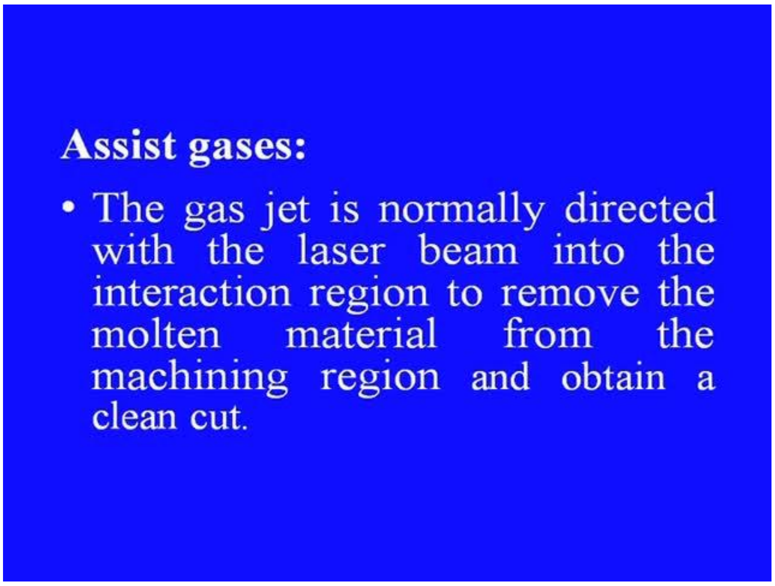

Then the affect of assist gases, the gas jet is normally directed with the laser beam into the interaction region, to remove the molten material from the machining region and obtain a clean cut assist gas should seal the lens system from the expelled material. As We have already discussed this pure oxygen causes rapid oxidation and exothermic reactions, causing better process efficiency. However, as far as the work material is concerned, if the cutting zone need not be oxidized or the or the chemistry of the cut zone need not be changed, then this may not be recommended or desirable.

In that case an inert gas such as helium or argon should be used and they are preferred if a cut edge of a better quality is required. It is important to note that the smaller the diameter of gas nozzle and the narrower its distance from the work-piece surface, the better is the quality of the cut. Gas pressure also plays a significant part in the determination of quality and rate of machining.

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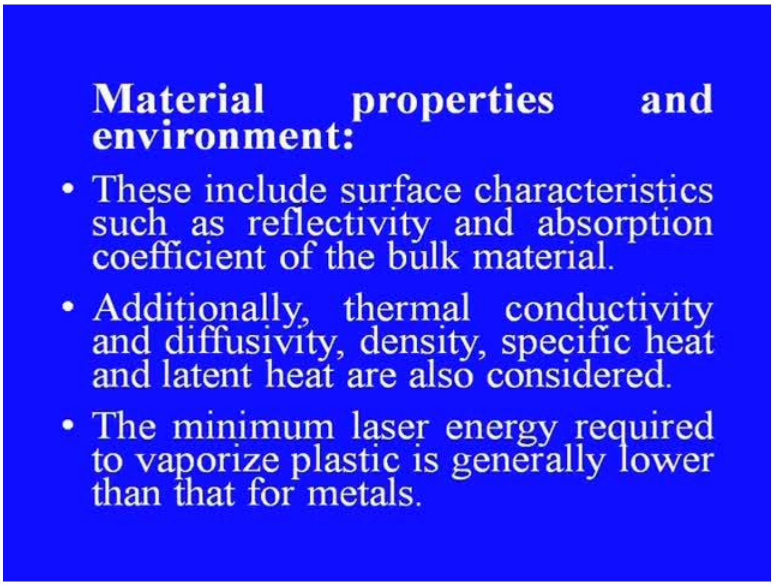

Material properties and environment also influences this quality of the drilled hole. These include surface characteristics, such as reflectivity and absorption. Coefficient of the bulk material on which the drilling is to be made additionally. Thermal conductivity and diffusivity density specific heat and latent heat are also to be considered. The minimum laser energy required to vaporize plastic is generally lower than that of metals. Therefore, accordingly the laser power is to be selected as per material requirement. Now, let us move on to the applications of laser beam machining.

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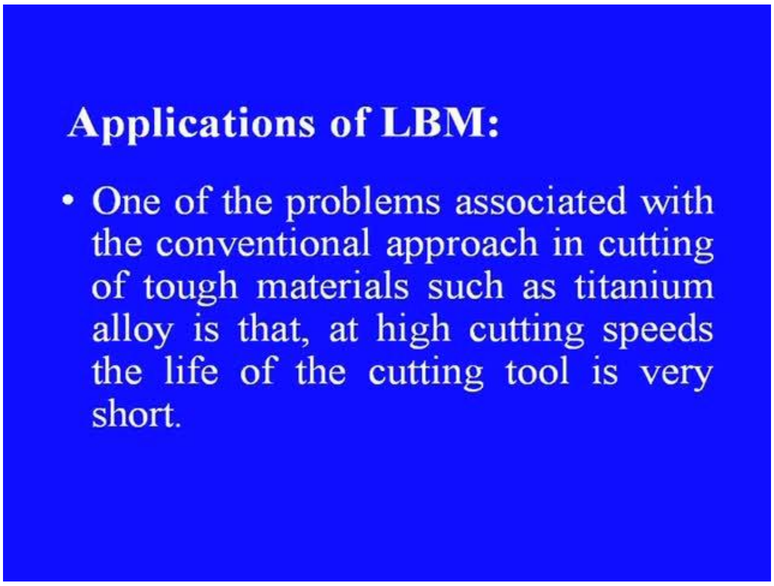

One of the problems associated with the conventional approach in cutting of tough materials such as titanium alloy is that at high cutting speeds, the life of the cutting tool is very short. As the titanium alloys are used extensively in the aerospace industry, there is a tremendous interest and curiosity for developing this technique, especially for enabling higher cutting rate. Nowadays, laser is also finding applications in regenerative machining or rapid prototyping as in processes like stereo lithography selective laser sintering SLS etcetera.

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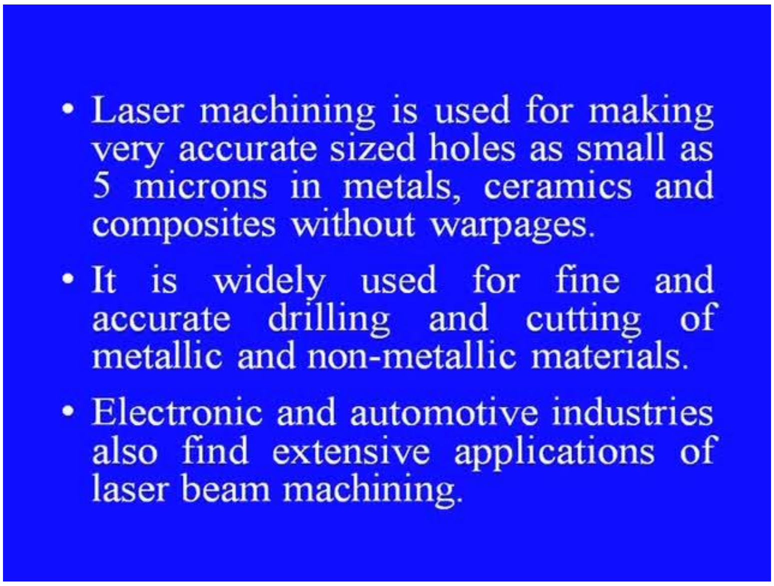

Laser machining is used for making very accurate sized holes as small as five microns in metals ceramics and composites without any war pages. It is widely used for fine and accurate drilling and cutting of metallic and non metallic materials. Electronic and automotive industries also find extensive applications of laser beam machining. The materials that can be cut by laser are extended to wood plastic leather glass ceramics and fiber optics. The next figure shows the schematic of cutting glass material through the laser machining process.

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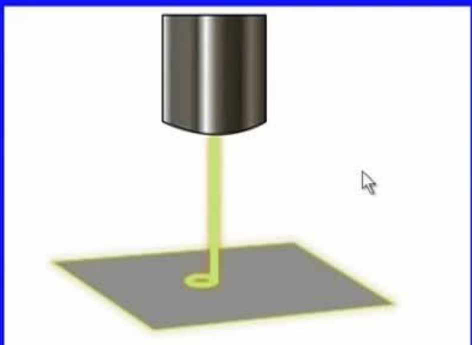

Figure-4 Laser Cutting of Glass

This is a glass material and this is the laser head and this can cut a hole or even a contour of required geometry. Then in cutting and grooving laser can be employed very efficiently powers in the range of 200 watt to 1 kilowatt are recommended. For cutting of steels oxygen jet assistance is found to be suitable for most metals, as the gas leverage additional energy by the exothermic chemical reactions that occurs in the machining region.

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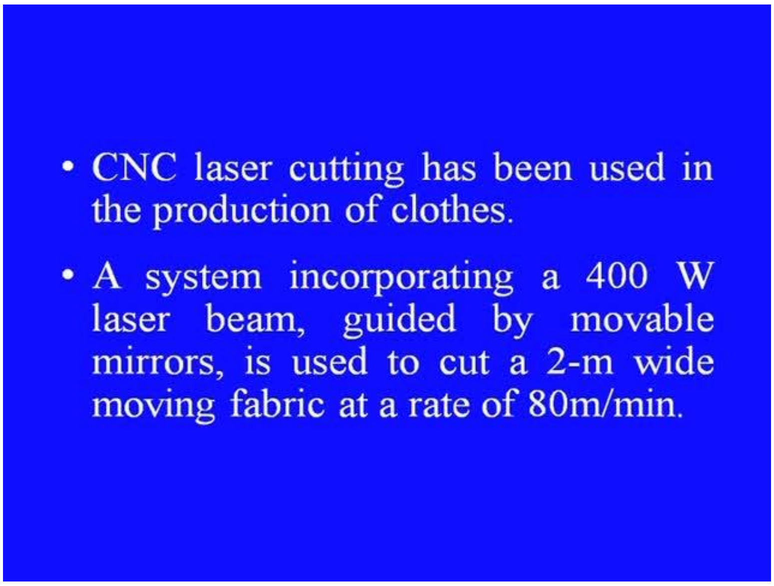

Computer numerical controlled laser cutting has been used in the production of clothes. A system incorporating a 400 watt laser beam guided by moveable mirrors is used to cut a 2 meter wide moving fabric at a rate of 80 meter per minute, which is quite high. Laser can also be used very effectively in texturing and structuring textured steel. Aluminum strips or sheets are widely used particularly among car manufacturers texturing facilitates lubrication during metal forming, and prevents adherence of sheets during annealing LBM has replaced conventional methods in many cases.

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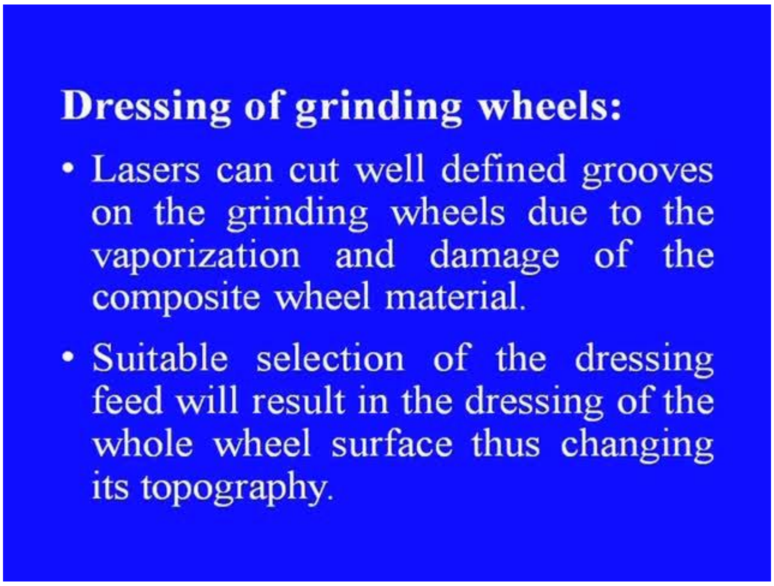

Laser beam machining can also be used in dressing of grinding wheels, which is very, very effective. Lasers can cut well defined grooves on the grinding wheels due to the vaporization and damage of the composite wheel material. Suitable selection of dressing feed will result in the dressing of the whole wheel surface thus changing its topography. The multiple cracks, which are induced thermally during laser dressing help to remove the re solidified layer during grinding, which then exposes new cutting edges. It is also possible to refresh the wheel by evaporating only the metals chips clogged on the wheel by focusing the laser beam, suitably by carefully selecting the controls of the laser beam. That is by carefully adjusting the beam intensity.

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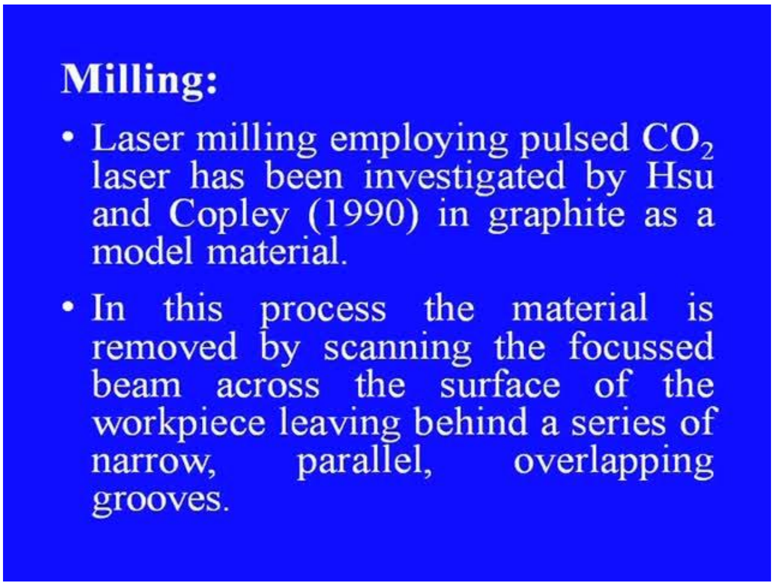

In milling also laser can be used very effectively. Laser milling employ pulsed carbon dioxide laser. It has been investigated by Hsu and Copley in the year 1990 itself. They have performed these experiments on graphite, in this process the material is used by scanning the focused beam across the surface leaving behind a series of narrow parallel overlapping grooves. Laser can also be used very effectively in fine cutting and drilling applications.

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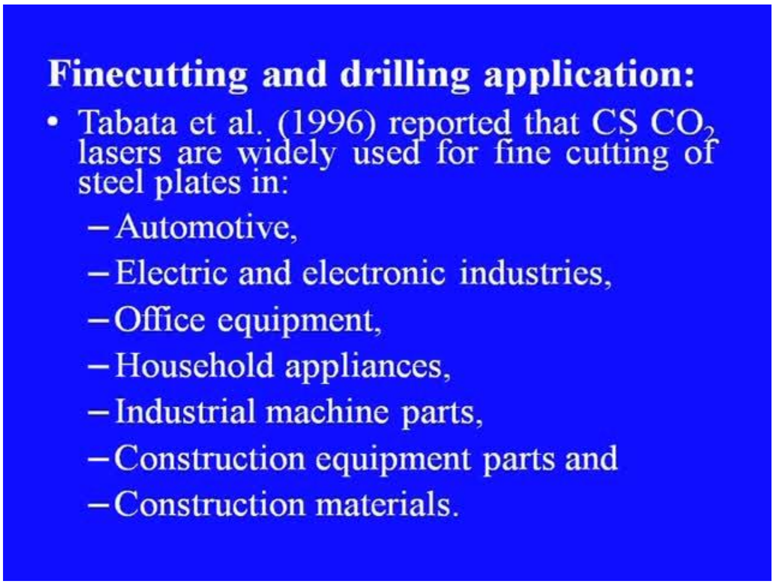

Tabata and his team mates in the year 1996 reported that carbon dioxide lasers are widely used for the cutting of steel plates in, automotive, electric and electronic industries, office equipment, household appliances, industrial machine parts, construction equipment parts and construction materials. The thickness of such cut steel plates range from 0.5 to even up to 16 mm. which is quite thick and the cutting speed carries 6 to 1 meter per minute in different cases.

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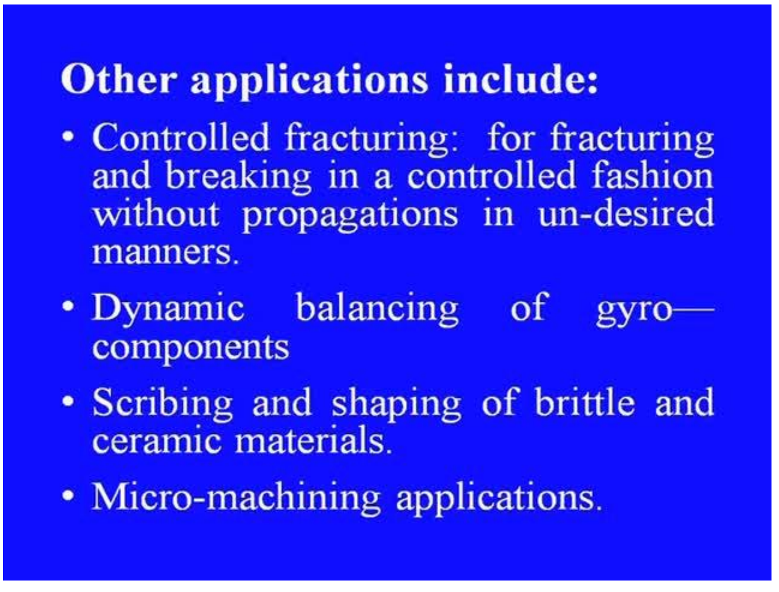

Some other applications include controlled fracturing. For fracturing and breaking in a controlled fashion without propagation in undesired manners. Then dynamic balancing of gyro components, scribing and shaping of brittle, and ceramic materials, micro machining applications etcetera. Now, let us summarize what we have discussed in this session. In this session we have discussed about the process parameters that affects the quality in laser beam machining, different advances in the laser machining processes and various applications of laser beam machining. We hope this session was informative and interesting.

Thank you.

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