Review on Laser Beam Machining(LBM) Process Parameter Optimization

Samir Joshi [1], Dr. S. A. Patil[2], Dr.A.M.Nikalje[3], Pawan Somavanshi[4]

[1]*M. E. Production mechanical engineering department,*
Government engineering college, Aurangabad.
[2] *Academic Dean, Government engineering college, Aurangabad*

Abstract-Laser Beam Cutting (LBM) is one of the most widely used manufacturing Field for generation of accurate and complex geometrical shapes on ferrous metal, non ferrous metal, stones, plastic and ceramics components with high dimensional accuracy. Fiber lasers are solid state laser technologies that offer a combination of high beam quality and a wavelength that is easily absorbed by metal surfaces. This work aims to evaluate the optimum laser cutting parameters for 0.5 mm thickness of EN10137-2 steel material sheets by using Fiber laser beam machine of 1000W Power as Focus of work is mainly on output response parameters Surface roughness SR. Results are analyzed using Analysis of Variance (ANOVA) technique. The effects of different input process parameters like laser power, Cutting Speed and gas pressure is studied on the output responses.

Key Words: LBM, Taguchi, ANOVA, SR, S/N Ratio, L-9 orthogonal array, Optimization.

1. INTRODUCTION-

Laser cutting is a technology that uses a laser to cut materials, and is typically used for industrial manufacturing applications. Laser cutting works by directing the output of a high- power laser most commonly through optics. The laser optics and CNC (computer numerical control) are used to direct the material or the laser beam generated The focused laser beam is directed at the material, which then either melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high- quality surface finish. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials.

Nowadays, production companies in high-wage countries face the challenge of meeting individual customer requirements and rapidly changing market demands while keeping costs low. Providing a reliable but efficient production leads to growing complexities in the production processes.

Production planning and scheduling requires a large amount of human information processing and decision making. In particular in the field of manufacturing process planning, decisions involve the consideration of the effect of multidimensional parameters on preselected criteria of the manufacturing process. For instance, one common problem is the choice of an appropriate machine parameter set those results in desirable process outputs (e.g. high output quality or minimal energy consumption). Due to a high dimensional domain space, the relationship between interdependent parameters and criteria is very difficult to achieve. In addition, they are very complex for the human mind to handle at a time. In order to handle these problems, process designers make use of modern computational approaches for modelling and simulating manufacturing processes. The conventional techniques to perform several sets of simulation run on the process, whereas each individual simulation is characterized by a high dimensional set of parameters and several criteria. The problem is that revealing the whole process behaviour requires a very large number of time-consuming experiments. It is not feasible to run full numerical simulations throughout the whole parameter space at a reasonable computational cost. Because of that, experimental simulation runs are performed by appropriate Design of Experiment (DoE) techniques as well as other, experience-based procedures. Since simulations are based on discrete sets of process parameters, they can only cover partial aspects of the process and do not provide insights into the whole process.

The laser beams are widely used for cutting, drilling, marking, welding, sintering and heat treatment. It is normally used for applications, ranging from military weapons to medical instruments, Cutting, Welding, Aerospace, Aeronautical industry. Materials which are cut by LBM are Al alloy, wood, ceramic, rubber, plastic, Brass, Hardox-400, etc

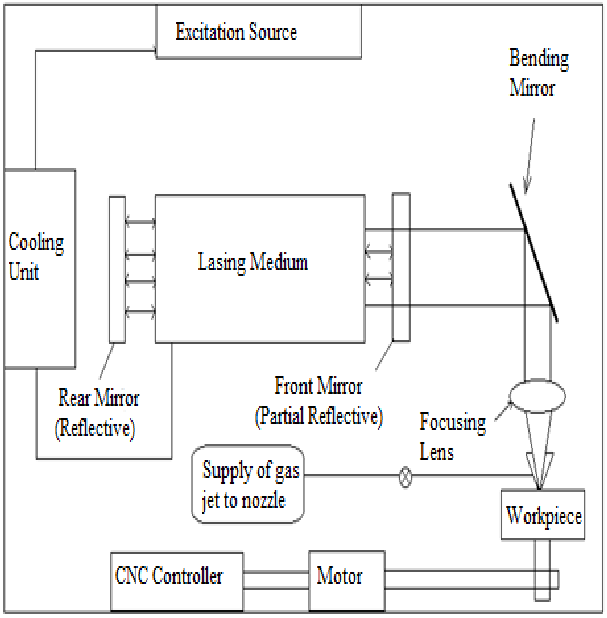


Fig. Laser Beam Machine Schematic diagram

2. LASER CUTTING PARAMETERS

The process of laser cutting involved many parameters, which can be generally divided into two main categories—beam parameters and process parameters

A. Beam Parameters

These are parameters that characterize the properties of the laser beam which include the wavelength, power, intensity and spot size, continue wave and pulsed power, beam polarization, types of beam, characteristics of beam, beam mode.

1. Wavelength

The wavelength depends on the transitions in the process of stimulated emission with respect to the physical mechanisms involves in energy coupling and the process efficiency, stability and quality, the wavelength plays a most decisive role. It has important effect on material's surface absorptivity. For a specific material type, there is a certain wavelength which can have maximum absorption of laser energy with a lowest reflection. Due to the shorter wavelength of fiber lasers (in the range of 1 μm almost the same as Nd-YAG laser) compared to CO2 lasers (10.6μm), it leads to the higher absorption in metallic material.

2. Power, intensity and spot size

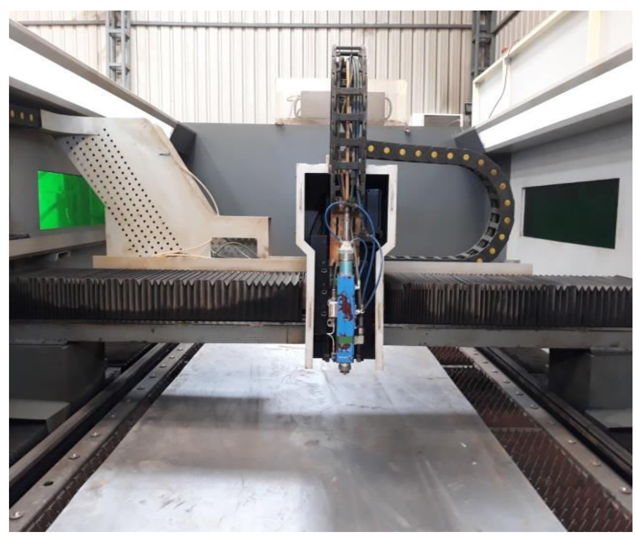
The size of a laser system is usually specified in the term of power. The power of laser system is the total energy emitted in the form of laser light per second. Without sufficient power, cutting cannot be started.

The intensity of the laser beam is the power divided by the area over which the power is concentrated. The high intensity of laser beam causes rapid heating of the material, which means that little time is available for heat to dissipate into the surrounding material. Additionally, the reflectivity of most metals is much lower at high intensities, compared to the low beam intensity. Moreover, the intensity determines the thickness of material which can be cut.

Spot size is the irradiated area of laser beam. In laser cutting application, it is required to focus beam into minimum spot size. Due to the better beam quality of fiber laser with very low divergence, the user can get spot diameters smaller than conventional lasers producing longer working distances.

3. Continuous wave (CW) and pulsed laser power

Both the continuous wave and pulsed laser power can achieve the high intensity needed for laser cutting. The cutting speed is determined by the average power level. Average power level with CW laser is higher compared to the pulsed laser.



B. Process Parameters

These are parameters that characterize the properties of the laser beam which include focusing of laser beams, focal position and dual focus lens, process gas and pressure, nozzle diameter, stand-off distance and alignment, and cutting speed.

1.Cutting Speed- When cutting speed is increases interaction between Laser beam and material is decreases. That is Heat generation decreases which leads to minimum side burning.

certain amount of energy to cause melting. However, striations on the cut edge become more prominent, dross is more likely to remain on the underside and penetration is lost. When the cutting speed is too low, excessive burning of the cut edge occurs, which degrades edge quality and increases the width of the HAZ. In general, cutting speed for a material is inversely proportional to the thickness.

2.Process Gas Pressure

By increasing the Gas pressure, the Heat Generated by exothermic is increased which results in self burning of the cut surface and hence the increase in the surface roughness.

When the pressure of the cutting gas is too high, the influence on the cutting quality: the cutting surface is rough, and the slit is wide; at the same time, the cut section is partially melted, and a good cutting section cannot be formed When the pressure of the cutting gas is insufficient, the following effects will be affected on th cutting quality: the melting will occur during cutting, and the cutting speed cannot meet the production efficiency

The process gas has five principle functions during laser cutting. An inert gas such as nitrogen expels molten material without allowing drops to solidify on the underside (dross) while an active gas such as oxygen participates in an exothermic reaction with the material. The gas also acts to suppress the formation of plasma when cutting thick sections with high beam intensities and focusing optics are protected from spatter by the gas flow. The cut edge is cooled by the gas flow thus restricting the width of the HAZ. The commonly used gases are the oxygen and nitrogen. Nitrogen is mainly used for stainless steel and aluminum, whereas the oxygen is used for mild steel.

In the process of oxygen cutting, the presence of oxygen contributes to an exothermic reaction, which effectively increases the laser power. It results into high cutting speeds and the ability to cut thick material. When cutting thick material, the gas pressure must decrease with the increasing thickness, in order to avoid the burning effect, whereas the nozzle diameter is increased.

3.Laser Power

Surface roughness value decreases with increase in cutting laser power, In general, it is evident that the surface roughness decreases with an increase in cutting speed . A decrease in laser power, generally increases surface roughness, however the effect of laser power should be considered through interaction with cutting speed and assist gas pressure. The cutting speed must be balanced with the gas flow rate and the power. As cutting speed increases, the cutting time decreases and less time for the heat to diffuse sideways and the narrower the HAZ. The kerf isalso reduced due to the need to deposit

Similarly, an increase in gas pressure increases surface roughness. The effects of cutting speed and assist gas pressure were more pronounced than the effect of laser power on surface roughness characteristics

4. Focusing of Laser Beams

The focal length of lens is about the distance from the position of focal lens to the focal spot. In the fiber laser system, the laser beam is delivered by the fiber optics and use a collimator to form the divergent laser beam. After that, it comes to the focusing lens or mirror and it focuses the parallel laser beam onto the work piece. The cutting process requires the spot size is small enough to produce the high intensity power. The focal length of the lens has a large impact on size of the focal spot and the beam intensity in the spot

5. Focal Position

In order to get optimum cutting result, the focal point position must be controlled. There are two reasons: the first reason is that the small spot size obtained by focusing the laser beam results in a short depth of focus, so the focal point has to be positioned rather precisely with respect to the surface of the work piece; the other one is differences in material and thickness may require focus point position alterations [4].

6. Nozzle Diameter, Stand-Off Distance

Nozzle is used to deliver the assist gas. The nozzle has three main functions in the laser cutting process: to ensure that the gas is coaxial with the beam; to reduce the pressure to minimize lens movements and misalignments; and to stabilize the pressure on the work piece surface to minimize turbulence in the melt pool.

The stand-off distance, which is the distance between the nozzle and the work piece, is also an important parameter. The stand-off distance is usually selected in the same range as the diameter of cutting nozzle-between 0.5 and 1.5 mm-in order to minimize turbulence. A short stand-off distance provides stable cutting conditions, although the risk of damage to the lens from spatter is increased. The stand-off distance is optimized to maximum the cutting speed and quality.

3. LITERATURE REVIEW

M. Buhujlbene-High power CO2 laser cutting of 6 mm thick of the low carbon steel sheets (S235) is investigated with the aim of evaluating the effect of the various laser cutting parameters such as laser power and cutting speed, on the laser cutting quality. In this study, cutting quality was evaluated by measuring the Quadratic mean roughness Rq of the machined surface. A simple and practical model was proposed to predict the Quadratic mean roughness Rq as a function of namely parameters; laser power P, cutting speed V and fixed assistance oxygen flow rate Q. The adequacy of the proposed model was tested by Analysis Of Variance (ANOVA). The Experimental data were compared with modeling data to verify the capability of the propose model.result indicate that laser power and cutting speed are determinant cutting parameter on the cutting surface. the surface roughness parameter is determined from ANOVA statistical analysis by providing simple analytical method.

Laser cutting operations for the purpose of the experiment are carried out on structural steel sheet (grade S235 LAC (E24-10037)) in order to produce, with the AMADA FANUC AF 2000C machine, 27 small samples, with dimensions of 30 mm in length, 10 mm in width and 6 mm in thickness. The chemical composition and the basic mechanical proprieties of the low carbon steel S235 samples.

Milos Madic- The laser cutting experiment was performed by means of ByVention 3015 (Bystronic) CO2 laser, delivering a maximum output power of 2.2 kW at a wavelength of 10.6 µm, operating in CW mode. The cuts were performed with a Gaussian distribution beam mode (TEM00) on 2 mm thick S355J2G3 (EN) mild steel using the oxygen as assist gas with purity of 99.95%. In consideration of the numerous parameters that influence cutting process and finally cut quality i.e. surface roughness, some of the process parameters were kept constant through the experimentation. A focusing lens with a focal length of 5 in. (127 mm) was used to perform the cut. The conical shape nozzle (HK10) with nozzle diameter of 1 mm was used. The nozzle–work piece stand-off distance was controlled at 0.7 mm. On the other hand, the main cutting parameters such as cutting speed (v), laser power (P) and assist gas pressure (p) were taken as variable input parameters. To cover wider range of laser cutting parameters that are controlled by the operator, these parameters were varied on 5 levels about 40% above and below their nominal operating level.

Kumavat Mukesh Manilal- In this study we are working on laser processing parameters and its optimization. To improve time required for process, improve surface hardness with minimum input of power as well as reinforced material quantity. This work is completely for metal surface hardness by laser with constant power input. We also work on surface roughness and its effect. Laser, Surface Roughness, Gas, Sheet Thickness, Focal Point

Sheet metal of stainless steel and mild steel are the project material on which we perform the practical in order to study the effect of variation of the parameters. There are several advantage of laser cutting over mechanical cutting, since the cut is performed by the laser beam, there is no physical contact with the material therefore contaminates cannot enter or embed into the material. Laser cutting can produce high quality cut, complex cut, cut several part simultaneously, produce clean cutting edge which require minimal finishing as well as low edge load during cutting which will reduce distortion Laser cutting is a fairly new technology that allows metals to be cut with extreme precision. The laser beam is typically 0.2 mm in diameter with a power of 1-10 kW, Depending on the application of the laser cutter a selection of different gases are used in conjunction with the cutting. When cutting with oxygen, material is burned and vaporized when heated by the laser beam to ignition

Chirag Patel- Laser cutting is mostly a thermal process in which a focused laser beam is used to melt material in a localized area. A co-axial gas jet is used to eject t b he molten material from the cut and leave a clean edge. A continuous cut is produced by moving the laser beam or work piece and leave a clean edge. A particular characteristic of a laser cut is the formation of striations on the cut edge. These striations play an important part in laser cutting as they effectively control the edge roughness. Laser Beam Machining is widely used manufacturing technique utilized to perform cutting, engraving and welding operations on a wide variety of materials ranging from metals to plastics. In the present work an attempt has been made to study the effect of process parameters such as feed rate, input power and gas pressure of 3 levels of each parameter on the quality of the machined surface using laser beam on stainless steel. Design of experiments is implemented by using a full factorial design. The effect of the process parameters on response have been shown by means of main effect plots developed using ANOVA analysis. After Design of Experiment (DOE) by using full factorial method, the analysis will be carry by the Analysis Of Variance (ANOVA) method and optimization will be carry Response surface methodology.

Mr. Amitkumar D. Shinde- This study investigates the influence of Laser Beam Machining (LBM) process parameters on surface roughness and kerf width while machining Stainless Steel (SS 304). Laser Beam Machining (LBM) is a non conventional process in which material removal takes place through melting and vaporization of metal when the laser beam comes in contact with the metal surface. There are so many process parameters which affect the quality of machined surface cut by LBM. But, the laser power, cutting speed, assist gas pressure, nozzle distance, focal length, pulse frequency and pulse width are most important. However, the important performance measures in LBM are Surface Roughness (SR), Material Removal Rate (MRR), kerf width and Heat Affected Zone (HAZ). Experiments are carried out using L27 Orthogonal array by varying laser power, cutting speed and assist gas pressure for stainless steel SS 304 material. The results showed that the assist gas pressure and laser power are the most significant parameters affecting the surface roughness and kerf width respectively, whereas the influence of the cutting speed is much smaller.

Laser Beam Machining on Stainless Steel (SS 304) material is carried out by using F0M2 3015NT Laser machine with maximum output power of 2.5 KW. Nitrogen was used as an assist gas for cutting with 100% duty cycle. The size of the work piece is 200 mm x 150 mm and 20 mm x 20 mm slot were cut down from the plate of 5 mm thickness for surface roughness measurement and a central linear cut of 10mm was cut down on it to measure the kerf width. Experimental set-up of LBM process is

Hasan Tercan- In the field of manufacturing engineering, process designers conduct numerical simulation experiments to observe the impact of varying input parameters on certain outputs of a production process. The disadvantage of these simulations is that they are very time consuming and their results do not help to fully understand the underlying process. For instance, a common problem in planning processes is the choice of an appropriate machine parameter set that results in desirable process outputs. One way to overcome this problem is to use data mining techniques that extract previously unknown but valuable knowledge from simulation results. Our research examines the use of such techniques within the field of Virtual Production Intelligence (VPI). This paper proposes a novel approach for applying machine learning models, namely classification and regression trees, to design a laser cutting process. The evaluation shows that the models accurately identify regions in the multidimensional parameter space that increase the quality of the process (i.e. high cut quality). We implemented the models in the web-based VPI-platform, where the user is able to gain valuable insights into the laser cutting process with the aim of optimizing it.

Rajaram et al.conducted experiments on samples of 4130 steel with CO_2 laser cutting system and the combined effects of power and feed rate on kerf width, surface roughness, striation frequency and heat affected zone have been studied. Regression analysis was used to develop models that describe the effect of the independent process parameters on laser cut quality. For the range of operation conditions tested, it was observed that power had a major effect on kerf width and size of HAZ, while feed rate affects were secondary. On the other hand, it was found out that surface roughness and striation frequency were affected most by feed rate. Yilbas (2004) examined laser gas assisted cutting process and statistical method based on factorial analysis was introduced to identify the influence of cutting parameters on the resulting cut quality. International standards for thermal cutting were employed to identify the measurable variables when assessing the cut quality. Kerf width size was presented using scaling laws. Contribution of high temperature oxidation reaction in cutting due to assisting gas was accommodated in the analysis. An experiment was conducted to assess the cutting quality and validate the Kerf width predictions. It was found that increasing laser beam scanning speed reduced the Kerf width while Kerf width increased with increasing laser output power. The main effects of all the parameters employed had significant influence on the resulting cutting quality.

Karatas et conducted experiments on CO_2 laser for cutting of steel and influence of beam waist position relative to the work piece surface and the work piece thickness on the striation formation was examined. The kerf width was modeled using a lump parameter analysis. The measurements are composed with the experimental findings. SEM and optical microscopy were conducted to examine the cutting surfaces. It was found that beam waist position had significant effect on the kerf size and as the work piece thickness reduces, the relative location of beam waist position varied for the minimum kerf width.

Dubey and yadava conducted experiments on nickel based super alloy (SUPERNI 718) sheet using Nd: YAG laser machine. A hybrid approach of Taguchi method (TM) and principal component analysis (PCA) had been applied for multi-objective optimization (MOO) of pulsed Nd:YAG laser beam cutting (LBC) to achieve better cut qualities within existing resources. The three-quality characteristics kerf width, kerf deviation (along the length of cut), and kerf taper had been considered for simultaneous optimization. Initially, single-objective optimization had been performed using Taguchi method and then the signal-to-noise (S/N) ratios obtained from Taguchi method had been further used in PCA for multi-objective optimization. The responses at predicted optimum parameter level were in good agreement with the results of confirmation experiments conducted for verification tests.

Sobih et al. presented the results of a laser cutting study using a 1 kW single-mode fibre laser, a relative newcomer in the field of laser metal cutting. Striation-free laser cuts were demonstrated when cutting 1mm thick mild steel sheets. The elimination of striation formation was considered important, since it could open a variety of novel high-precision applications. It was observed that the surface roughness decreased as the cutting speed increased until an optimum cutting speed was reached. Beyond this the surface roughness gradually increased again.

Powell et al. (2011) presented the results of an experimental and theoretical investigation into the phenomenon of ‗striation free cutting', which is a feature of fibre laser/oxygen cutting of thin section mild steel. The author concluded that the creation of very low roughness edges was related to an optimization of the cut front geometry when the cut front was inclined at angles close to the Brewster angle for the laser– material combination. It was concluded by author that the lowest roughness mild steel cut edges are produced at intermediate speeds considerably lower than the maximum cutting speed.

Park et demonstrated an approach to improve laser machining quality on metals by vibrating the optical objective lens with a frequency (of 500Hz) and various displacements (0–

16.5 mm) during a femtosecond laser machining process. The laser used in this experiment was an amplified Ti: sapphire fs laser system that generated 100fs pulses having energy of 3.5mJ/pulse with a 5 kHz repetition rate at a central wavelength of 790nm. It was found that both the wall surface finish of the machined structures and the aspect ratio obtained using the frequency vibration assisted laser machining were improved, compared to those derived via laser machining without vibration assistance.

Rajpurohit and patel investigated and reviewed the striation mechanism which affect the quality of laser cutting and associated quality improvement techniques. Striation formation on the cut surfaces, which affects the surface roughness and geometry precision of laser cut product. An important weakness of this process is the formation of striations (regular lines down the cut surface), which affect the quality of the surfaces produced. It had been observed and found out by author that Control of striation could be achieved by stable melt flow from cutting front as well as intermediate cutting speed for a smooth cutting edge by optimization of the various process parameters like laser power, cutting speed and gas pressure which found out as major conflict the quality of cutting

4. REFERENCES

- ✓ Black, I., Livingstone, S.A.J. and Chua, K.L. (1998), ‗A laser beam machining (LBM) database for the cutting of ceramic tile', Journal of Materials Processing Technology, Vol. 84, pp. 47–55.
- ✓ Babic, I.D., Diduck, Q., Faili, F., Wasserbauer, J., Lowe, F., Francis, D. and Ejeckam, F. (2011), ‗Laser machining of GaN-on-diamond wafers', Diamond & Related Materials, Vol. 20, pp. 675-681.
- ✓ Chang, C.W. and Kuo, C.P. (2007), ‗Evaluation of surface roughness in laser-assisted machining of aluminum oxide ceramics with Taguchi method', International Journal of Machine Tools & Manufacture, Vol. 47, pp. 141-147.
- ✓ Cicala, E., Soveja, A., Sallamand, P., Grevey, D. and Jouvard, J.M. (2008), ‗The application of the random balance method in laser machining of metals', journal of materials processing technology, Vol. 196, pp. 393-401.
- ✓ Darvishi, S., Cubaud, T. and Longtin, J.P. (2012), ‗Ultrafast laser machining of tapered microchannels in glass and PDMS', Optics and Lasers in Engineering, Vol. 50, pp. 210-214.
- ✓ Dubey, A.K. and Yadava, V. (2008), ‗Experimental study
  - 8
- ✓ Book - Narendra B. Dahotre, Sandip P. Harimkar. Laser fabrication and machining of materials, Spinger-new york, ISBN 9780387723433 (2008)
- ✓ Book - Steen W., Laser Material Processing, Fourth Edition, London, 2010, Spinger - Verlag, ISBN 978-1-84996-061-8. pg 156-189
- ✓ M. Madic, M. Radovanovic, M. Trajanovic, M. Manic. Multi objective optimization of laser cutting using cuckoo search algorithm. Journal of Engineering Science and Technology 353-363.
- ✓ Dubey A.K.; and Yadava V. (2008). Laser beam machining - A review. International Journal of Machine Tools and Manufacture, 48(6), 609-628
- ✓ K. Venkatesana, R. Ramanujamb, P. Kuppanc. Analysis of Cutting Forces and Temperature in Laser Assisted Machining of Inconel 718 using Taguchi Method.
- ✓ M Lakshmi Chaitanya & A Gopal Krishna. Multi-

objective Optimization of Laser Beam Cutting Process

- ✓ Ruben Phipon & B.B.Pradhan. Control Parameters Optimization of Laser Beam Machining Using Genetic Algorithm. International Journal Of Computational Engineering Research (ijceronline.com) Vol. 2 Issue. 5
- ✓ Koji Hirano and Remy Fabbro. Experimental observation of hydrodynamics of melt layer and striation generation during laser cutting of steel, Physics Procedia 12 (2011) pg. 555–564 DOI:10.1016/j.phpro.2011.03.070
- ✓ Ramesh Singh, Shreyes N. Melkote. Characterization of a hybrid laser-assisted mechanical micromachining (LAMM) process for a difficult-to-machine material, International journal of machine tools & manufacture 47 (2007) page.1139–1150