



Theoretical aspects of Laser Processing of Composite Materials

Vikas Sharma¹, Vinod Kumar²

¹Assistant Professor, Mechanical Engineering Department, Chandigarh University, Punjab, INDIA.

²Associate Professor, Mechanical Engineering Department, Thapar University, Punjab, INDIA.

Abstract: Traditional machining methods become typical when the machining of composite materials is to be executed. In the current era basically two types of composite material namely polymer composites and metal matrix composite materials are used in industrial application. Poor machining quality and low productivity via conventional methods leads to the invention of new non-conventional machining methods. Laser machining methods are now a day's becoming popular for cutting of composite materials. Fast cutting speed and no contact with workpiece are some of the new qualities of laser cutting methods. In this article the major application of laser source in cutting of various materials is depicted in details.

Keywords: Non-conventional, composite material, metal matrix composites, laser source, polymer

I. Introduction:

In the current era laser cutting process is counted as state of art cutting technology due to its high efficiency and capability to cut complex shapes in a very high speed. A laser process expels the molten material out with the help of gases which may be oxygen and nitrogen depends on the material to be cut. It becomes important to reveal the important facts about laser cutting process and composite materials. Polymer composites consist of matrix as resin and fibers as reinforcement which cannot easily cut by non-traditional method with high accuracy and maximum cutting speed. On the other hand metal matrix composite materials also consists of two components like reinforced ceramic powders like SiC, Al₂O₃ etc. and base material like Aluminum etc. material removal rate for laser cutting process mainly depends upon melting and evaporation process.

II. Working principle of laser

Laser works by three processes with the help of different emission and absorption processes. These processes come in role when photon reaches in different states. Three processes explain how electron and photons help in production of laser which is illustrated in figure 1(a,b,c). For instance when any electron reaches in an excited energy state, and releases energy in the form of photon by coming at lower levels. This process is called spontaneous emission [1]. The most important process stimulated emission occurs when electron having energy level E₂ and decay direction to E₁, then a photon losses whole energy in form of E₂-E₁. The details of various laser source machining systems are followings:

A. CO₂ laser

CO₂ laser systems are basically used in worldwide due to its capability to cut large thickness materials with high accuracy and cutting speed. The CO₂ medium is basically used to combine with two gases namely nitrogen and helium. Nitrogen plays a vital role in production of laser with high intensity. Nitrogen molecules produce the excited state for CO₂ molecules whereas helium molecules increase the excited levels of lower energy gained CO₂ molecules. The wavelength of this system lies in the range of 10 μm which makes it difficult to penetrate in the highly reflective materials like aluminium of high thickness.

B. Nd:YAG laser

Neodymium and Yttrium Aluminium Garnet system lies in the category of solid state laser system. In this system Nd:YAG rod and mirrors (works as an oscillator) plays a important role to regulate the laser light. This system has given a new revolution to the industries with less power consumption as compare to CO₂ laser system. The wavelength of this system is 1.06 μm, which makes it capable to penetrate into the material of high reflective nature.

C. Fibre and Excimer laser

Fiber laser is another laser system which also given new industrial revolution to industries. This system mainly consists of fiber optics structure where fiber core, cladding and layer between core and cladding create a system to generate the high power laser. Excimer basically termed on the basis of mixture of atoms which remain in excited state. This system consists of halogen molecules and various gases like xenon, krypton etc. These types of laser system basically used in medical field where the surgery or ablation of skin is to be executed. The lowest spot size of this type of laser makes perfect use in the bio-firms.

III. Literature review

With the invention of many engineering materials, the machining processes also have to be efficient for these materials and laser cutting process is one of the successful methods for these materials. Many researchers have carried out work on composite materials to analyse the effect of various parameters on quality characteristics with the help of optimization techniques. The laser cut-edge quality mainly depends upon the constituents of polymer composites was studied by Cenna *et al.* [2]. It was analysed that aramid fiber reinforced plastic (AFRP) composites have better cut edge quality than the carbon fiber reinforced plastic (CFRP). They proposed that AFRP has the polymeric nature between fiber reinforcement and matrix material whereas CFRP had low quality due to different thermal nature of matrix and fiber material. Lum *et al.* [3] investigated the CO₂ laser cutting of medium-density fibreboard (MDF) by varying various input parameters using continuous wave (CW) and pulse mode (PM). They revealed that the surface roughness increased with an increase in cutting speed. Also proposed that Kerf width depends upon various factors namely are the laser and material interaction time, power, nozzle distance and material composition. Sulaiman *et al.* [4] examined the laser cutting of carbon fiber composite material. they investigated two main results, i) kerf width size increases with laser power ii) orientation of carbon fibers w.r.t workpiece responsible for change in kerf width size. The SEM images as shown in figure 2(a,b) revealed about striation pattern on the cutting surface when workpiece movements are normal and parallel to fiber axis.

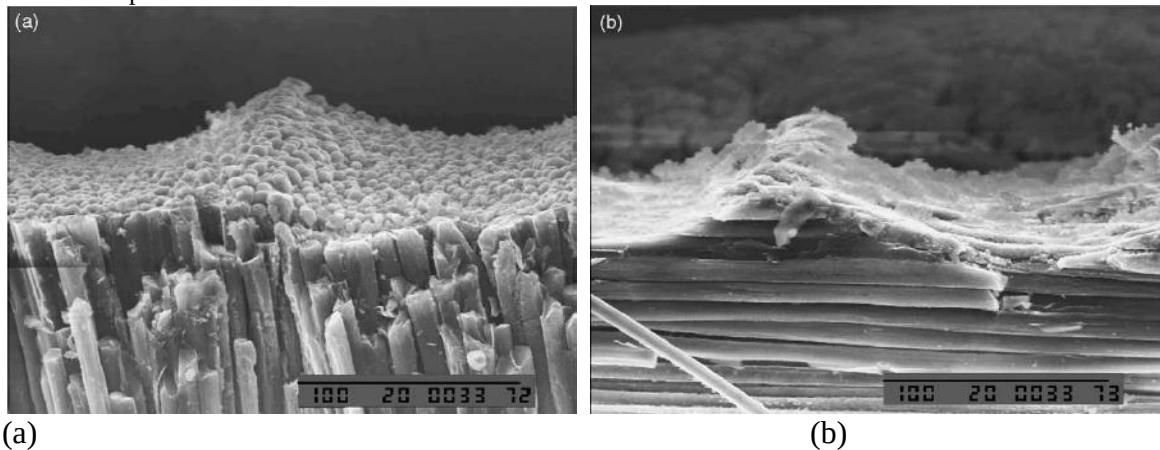


Figure 2 SEM images shows striation patterns according to workpiece motion(W.M) when: (a) W.M normal to fiber principle axis and (b) W.M parallel to fiber principle axis [3]

Quintero *et al.* [5] studied about CO₂ laser cutting process of phenolic resin boards. They investigated that laser power of 3 kW and cutting speed of 3.5 m/min optimum for clear cutting of plastic boards. It was also examined that cut edge was accumulated with burned residuals which may be caused due to the ejected gases during the laser cutting process. Eltawahni *et al.* [6] investigated CO₂ laser cutting of medium density fibre board(MDF) by varying various input laser cutting parameters. It was examined that with the increase of pressure, cutting speed and focal point average upper kerf width decreased whereas focal point position was most responsible factor for significant change in kerf width. Tagliaferri *et al.* [7] explored that reinforcements fiber have high vaporizing temperature as compared to the plastic resin. Also examined that thermoset resin required high energy to get vaporize as compared to thermoplastics. Black *et al.* [8] investigated the CO₂ laser cutting of ceramic tiles and proposed the optimum parameters for various quality characteristics. They examined the effect of different gases on the quality characteristics and also provided some results related to multi-pass and underwater cutting. Mathew *et al.* [9] proposed the cause and effect diagram based on the observations of laser cutting of Fiber reinforced plastics (FRP). Cenna *et al.* [10] investigated the relation between power density and interaction time of various composite materials and found that graphite has larger interaction time and power intensity to vaporize. Figure 4 illustrated the relationship between power density and interaction time. Chen *et al.* [11] explored that carbon fibers and resin matrix decomposed easily and quickly in oxidative medium when the gaseous reactions are purely exothermic in nature. Ashby *et al.* [12] examined that thermosetting epoxies when exposed to heating process like laser cutting, then the melting and viscous nature of epoxies assumed to be negligible. They proposed that due to cross-linked and amorphous nature these epoxies shows this type of decomposed nature.

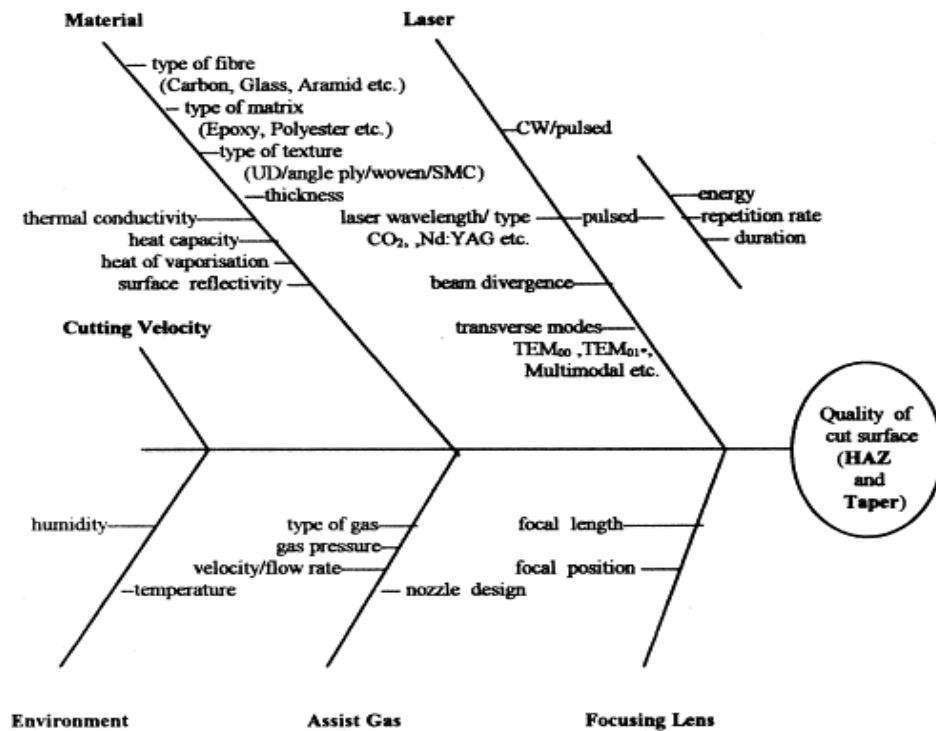


Figure 3 Effect of various parameters on output responses like Haz and Kerf Taper [9]

Chen *et al.*[13] analysed heat affected zone by developing FEM model for various composites materials like Glass, Kevlar and Carbon fiber. This finite element model was based on relationship between temperature and time intervals. Newnham *et al.* [14] developed 2-dimensional model on the basis finite element analysis for carbon fiber reinforced plastics. They developed typical temperature model without considering the metal removal rate. Halpin *et al.* [15] examined about anisotropic properties of carbon fiber reinforced plastics. They also revealed that anisotropic depends on fiber properties like fiber geometry, fiber orientation and volume fraction.

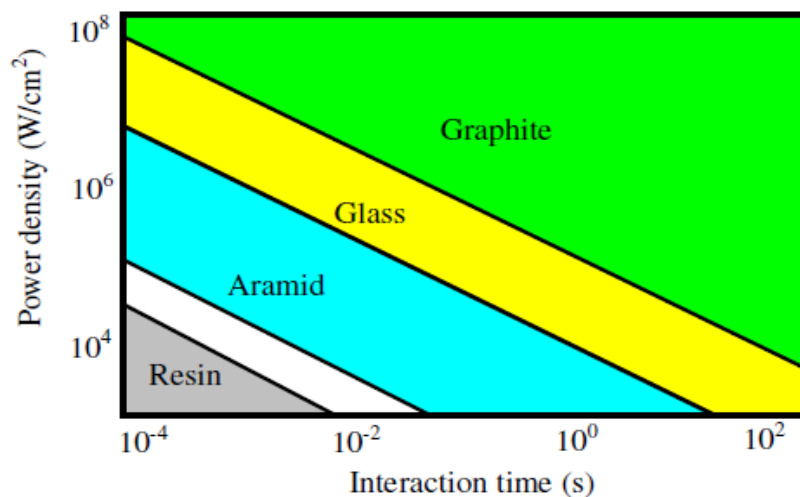


Figure 4 Interaction time with various materials according to power density [10]

IV. Conclusions

Laser cutting systems are one of the best machining systems which perform the task without compromising the higher productivity, cutting quality and higher accuracy. With the traditional system the delamination factor was considered as most typical point to remove but with the application of these current laser source systems this problem reduced in large extent. Despite of different vaporizing and melting temperature of constituents of polymer composite the laser systems are able to create the new path in this context.

References

- [1] Introduction to Laser Technology, Melles Griot, article 36, 2003, 1-25.
- [2] Cenna AA, Mathew P. ,Evaluation of cut quality of fibre-reinforced plastics: a review. International Journal of Machine Tools and Manufacture vol.37, 1997, 723–736.
- [3] K.C.P. Lum, S.L. Ng, I. Black, CO₂ laser cutting of MDF , Determination of process parameter settings, Journal of Materials Processing Technology 173, 2006, 345–351.
- [4] Sulaiman F.A. Al-, Yilbas B.S. , Ahsan M., CO₂ laser cutting of a carbon/carbon multi-lamelled plain-weave structure, Journal of Materials Processing Technology, 173, 2006, 345–351
- [5] Quinteroa F., Riveiroa A., Lusquinosa F., Comesa R, Poua J., CO₂ laser cutting of phenolic resin boards, Journal of Materials Processing Technology 211, 2011, 1710– 1718
- [6] Eltawahni n H.A., Olabi A.G., Benyounis K.Y.,Investigating the CO₂ laser cutting parameters of MDF wood composite material, Optics & Laser Technology, 43, 2011, 648–659
- [7] Tagliaferri, V., A. Di Ilio and Visconti I.C., Laser cutting of fibre-reinforced polyesters. Composites, vol. 16, 1985, 317-325.
- [8] Black I. , Livingstone S.A.J., Chua K.L., A laser beam machining (LBM) database for the cutting of ceramic tile, Journal of Materials Processing Technology 84, 1998, 47–55
- [9] Mathew, J., G.L. Goswami, N. Ramakrishnan and N.K. Naik, Parametric studies on pulsed Nd:YAG laser cutting of carbon fibre reinforced plastic composites. Journal of Material Processing Technology, vol. 89-90, 1999, 198-203.
- [10] Cenna, A.A. and P. Mathew, Evaluation of cut quality of fibre reinforced plastics-a review. International Journal of Machine Tools and Manufacture, vol. 37, 1997, 723-736.
- [11] Chen, K.S., R.Z. Yeh and C.H. Wu, Kinetics of thermal decomposition of epoxy resin in nitrogen-oxygen atmosphere. Journal of Environmental Engineering, vol.123, 1997, 1041-1046.
- [12] Ashb, M.F. and D.R.H. Jones, An introduction to microstructures, processing and design. Engineering materials 2: 2nd ed. 1998: Butterworth-Heinemann.
- [13] Chen, C.C. and W. Cheng. Material properties and laser cutting of composites.in 23rd International Technical Conference. 1991. Covina, CA, USA
- [14] Newnham, P. and S. Abrate, Finite element analysis of heat transfer in anisotropic solids: application to manufacturing problems. Journal of Reinforced Plastics and Composites, vol. 12, 1993, 854-864.
- [15] Halpin, J.C., Primer on composite materials: Analysis., USA: Technomic Publishing Company. 1984, 1-124.