International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 3, March - 2014

Grey Relational Analysis Based Optimization of Laser Cutting Process Parameters for Aluminium Alloy - A Review

Rahul D. Patel
M.Tech. Scholar, Mech. (AMT) Dept.
U.V.Patel Engg. College
Kherva, India

Prof. Dr. D. M. Patel
Principal, SSESGI, Rajpur, India

Abstract **- Unconventional machining processes are used only when no other traditional process can meet the necessary requirements efficiently and economically. Determinations of machining parameters are essential for the effective utilization of these processes. Laser cutting is a thermal cutting process in which a cut kerf (slot) is formed by the heating action of a focused traversing laser beam. This paper presents literature review of previous work done by the researchers based on laser cutting process for parametric optimization using different techniques. One researcher's results are reviewed for optimum kerf qualities.**

Keywords— Unconventional machining, Laser cutting process, Optimization.

I. INTRODUCTION

1.1 Laser

LASER is the acronym for Light Amplification by Stimulated Emission of Radiation. Albert Einstein first explained the theory of stimulated emission in 1916, which became the basis of Laser [1]. The development of Lasers has been a turning point in the history of science and engineering. It has produced a completely new type of systems with potentials for applications in a wide variety of fields.

Laser has been generated on the principle of stimulated emission. Electrons can transit to other energy levels by absorbing or releasing energy. For example, after an electron has absorbed a photon, it transits from a lower energy level to a higher one. Electrons transit between energy levels by absorbing or emitting light.[2] Monochromaticity, coherence and collimation are the properties of laser beam.[3] Laser is constructed from three principle parts such as, (1) Pump source like, electrical discharges, flash lamps, arc lamps, light from another laser etc. (2) gain medium or laser medium like, liquids, solids, semi-conductors etc. (3) Optical resonator, it is two parallel mirrors placed around the gain medium which provide feedback of the light.[4] Lasers have now found applications in welding, cutting, drilling, micro-machining, defense, marking, scribing, paint striping, surface removal, in the field of medicines, metal deposition, heat treating, commercial applications etc.[5],[6]

1.2 Laser Cutting Process

Laser cutting is a thermal cutting process in which a cut kerf (slot) is formed by the heating action of a focused traversing laser beam of power density on the order of 10^4 W/mm^2 in combination with the melt shearing action of a stream of inert or active assist gas. The focused laser beam melts the material throughout the material thickness and a pressurized gas jet, acting coaxially with the laser beam, blows away the molten material from the cut kerf as shown in fig. 1.[7]

Laser cutting of any material is done by following three processes: (1) Laser fusion cutting, (2) Laser oxygen cutting and (3) Laser vaporization cutting. [7] Laser cutting process has been found an application in micromachining; resize silicon wafers for solar panels, 2-D profile cutting in sheet metals, tube cutting, 3-D cutting etc.

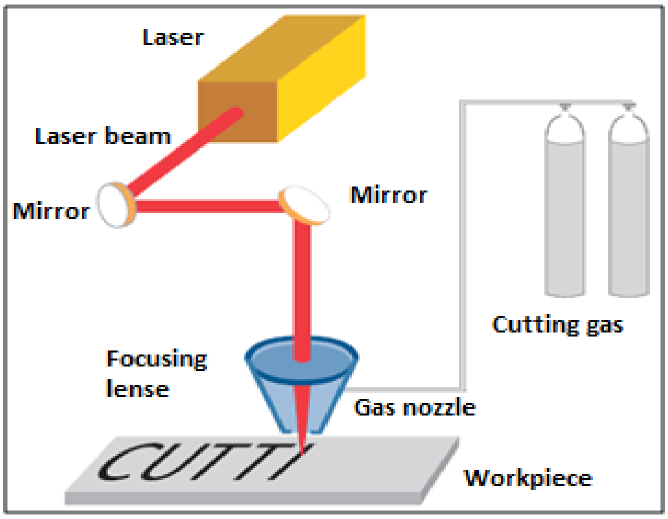

Fig.1 Laser cutting system [8]

1.3 Grey Relational Analysis

Grey relational analysis is used for optimization of multi performance characteristics. In grey relational analysis, experimental data i.e. measured features of quality characteristics of the product are first normalized ranging from zero to one. This process is known as grey relational generation. Next, based on normalized experimental data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation, with the objective function is overall grey relational grade. The optimal parametric combination is then evaluated by maximizing the overall grey relational grade. [9]

II. LITERATURE SURVEY

Literature review provides the scope for the present study. Literature review should contain academic journals, Government reports, Books, The earlier research studies relevant to research problem. Literature review provides the data to narrow the problem itself as well as the techniques that might be used. This would also help a researcher to know if there are certain gaps.

S. Nagesh et al. have concentrated on improving the quality of CO_2 laser drilled holes in composite materials. The objective of this research was to investigate the effect of carbon black along with laser parameters such as laser power, pulse frequency, and scanning speed on Heat affected zone and Taper angle of laser drilled hole based on L16 orthogonal array lay-out. They have optimized HAZ and Taper angle using Grey Relational Analysis. By results, it is shown that HAZ and TA were mainly influenced by Carbon black and Laser Power. Combination of greater Carbon black and lower Laser power yields lower HAZ. Minimum TA was achieved at higher Laser power. ANOVA also resulted with the importance to Carbon black and Laser power. Regression equations were generated to predict HAZ and TA.[10]

A. Bharatish et al. has discussed the hole circularity and Heat affected zone in pulsed CO2 laser drilling of alumina ceramics. This paper shows that circularity of drilled hole at entry and exit, heat affected zone and taper are important attributes which influence the quality of a drilled hole in laser drilling. Heat affected zone was influenced by frequency. Taper was also significantly influenced by laser power. Response surface model predicted nominal entrance circularity at 2.5 kHz, 240W, 2.5 mm/s, 1 mm hole, exit circularity and taper at 7.5 kHz, 240W, 4.5 mm/s, and 1 mm hole. The model predicted lowest heat affected zone at 7.5 kHz, 240W, 2.5 mm/s, and 1 mm. Multiobjective optimization achieved using both response surface model and gray relational analysis indicated that all the four quality parameters are optimized at 7.5 kHz, 240W, 3.85 mm/s and 1 mm.[11]

Ulas Caydas & Ahmet Hascalik have presented an effective approach for optimization of laser cutting process of st-37 steel of CO_2 laser with multiple performance characteristics based on the grey relational analysis. The purpose of this work was to introduce the use of grey relational analysis in selecting optimal laser cutting conditions on multi performance characteristics. In this study, the laser cutting parameters such as laser power and cutting speed are optimized with consideration of multiple performance characteristics, such as workpiece surface roughness, top kerf width and width of heat affected zone (HAZ) as shown in Fig. 2. By analyzing the grey relational grade, it is observed that the laser power has more effect on responses rather than cutting speed. [9]

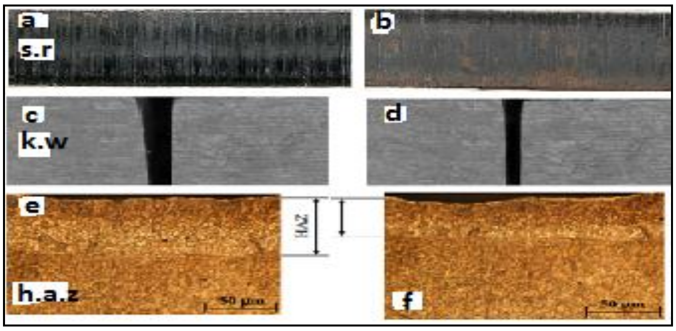

Fig.2 Measured performances before & after optimal cutting

T. M. Chenthil Jegan et al. has discussed determination of Electro Discharge Machining parameters in AISI202 Stainless Steel using Grey relational analysis. This paper describes the selection of machining parameters Discharge current, Pulse ON time and Pulse OFF time in EDM for the machining of AISI202 stainless steel material. In this paper, the use of Grey relational analysis for optimizing the machining parameters Material removal rate and Surface roughness was introduced. Grey relational analysis was applied to find the Grey relational grade and Grey relational grade was used to find the optimal parameters. The results show that Discharge current was the main parameter affecting the MRR. Hence by properly adjusting the control factors, work efficiency and product quality can be increased. [12]

Milos MADIC et al. demonstrated the application of Taguchi method for optimization of surface roughness in CO2 laser cutting of 2mm thick mild steel. The experiment was designed and carried out on the basis of standard L25 Taguchi's orthogonal array in which three laser cutting parameters such as the cutting speed, laser power and assist gas pressure were arranged at five levels. The results showed that the cutting speed and assist gas pressure were the most significant parameters affecting the surface roughness, whereas the influence of the laser power was much smaller. The ANOVA resulted in less than 5% error indicating that the interaction effects of the laser cutting parameters are negligible. [13]

Arindam Ghosal & Alakesh Manna has presented the paper on machining of Al/Al_2O_3-MMC by ytterbium fiber laser. A comprehensive mathematical models for correlating the interactive and higher-order influences of various machining parameters such as laser power, modulation frequency, gas pressure, wait time, pulse width on the machining performance criteria e.g., metal removal rate and tapering phenomena has been developed for achieving controlled over fiber laser machining process. The response surface methodology (RSM) was employed to achieve optimum responses i.e., minimum tapering and maximum material removal rate. The influences of the various process parameters of ytterbium fiber laser on both the responses i.e., MRR and taper during laser machining of 5mm thick Al/10wt% Al2O3-MMC have been analyzed based on the developed mathematical models established utilizing response surface methodology (RSM). The optimal parametric combination for maximized MRR and minimized taper was 473.12W laser power, 604.54 Hz modulation frequency, 19.82 bar nitrogen gas pressure, 0.18 s wait time and 93.47% pulse width. [14]

D. Whitehead et al. has discussed the Comparison of dry and wet fiber laser profile cutting of thin 316L stainless steel tubes for medical device applications. They have used fiber laser for stent cutting. Dry cutting has been performed with the presence of the N2 assist gas, and the wet cutting was performed with the presence of an assist gas (N2) and continuous water flow through the inner part of the tube along the tube axis. They have taken Peak pulse power (W), Frequency (kHz), Pulse width (ms), Cutting speed (mm/min) as input parameters. The cutting quality factors investigated were kerf width, surface roughness, dross deposition, back wall damage and heat affected zone (HAZ). When water flow was introduced in the tubes, back wall damage was prevented. Meanwhile, heat affected zone (HAZ), kerf width, surface roughness and dross deposition have also been improved compared with the dry cutting. Significant improvements with wet cutting to minimize the heat effect and back wall damage were achieved in this work. Wet cutting resulted in narrower kerf width, lower surface roughness, less dross, absence of back wall damages and smaller HAZ in Fig.3. [15]

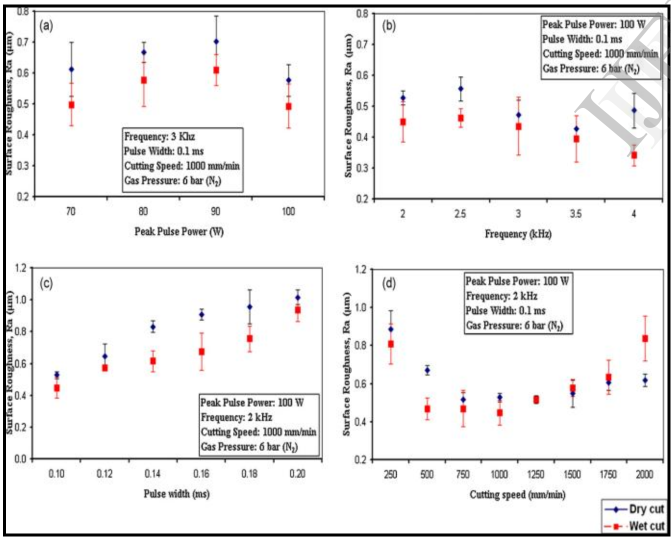

Fig. 3 Surface roughness as a function of laser cutting parameter in dry and wet cutting: (a) peak pulse power, (b) frequency, (c) pulse width and (d) cutting speed

Hanadi G. Salem et al. evaluated the CW Nd:YAG laser cutting parameters such as gas - pressure, laser power, and scanning speed for 1.2mm thick ultra-low carbon steel sheets using O_2 assist gas. The effect of the cutting parameters on the cut quality was then investigated, by monitoring the variation in hardness, oxide layer width and microstructural changes within the heat affected zone (HAZ). The laser power was varied within the range of 337–515W, the scanning speed varied within the range of 700–1500 mm/min, and the assist oxygen gas pressure range was 3.5–5 bar. From the results they have concluded that for laser cutting of ultra low carbon steel sheets of 1.2mmthick, it is recommended to use the laser power of 337W and high scan speeds within 1000–1500mm/min when oxygen is used as assist gas at 5 bar. Thinner or thicker sections would require different ranges of laser power and scanning speeds. [16]

Mayank N Madia & Prof. Dhaval M Patel has investigated the effect of Focal length on Surface roughness of 1mm thin Brass sheet using nitrogen (N_2) as assist gas. The Laser cutting characteristics including power level and focal length are investigated in order to obtain surface roughness with maximum cutting speed. The surface roughness was investigated for a laser power range of 1000–1500W and focal length 122-132mm, gas pressure 18 bar constant for brass materials. The full factorial method was used for cutting speed and surface roughness. Result revealed that good quality cuts can be produced in brass sheets, at a window of laser power 1500 watt and focal length 122 mm, the surface roughness was 1.941μm and 7500mm/min cutting speed was achieved. ANOVA was used to find out the percentage contribution of input parameters for Surface roughness. As per ANOVA, focal length was most significant factor for Surface Roughness of brass 1 mm thin sheet. [17]

S. Stelzer et al. have presented experimental investigations on fusion cutting stainless steel with fiber and CO_2 laser beams. The experiments were conducted on AISI 304 stainless steel sheets in the thickness range between 1 and 10 mm. The experiments were conducted for maximum cutting speed, cut edge surface roughness and cut kerf geometry and compared for both CO_2 and Fiber lasers. From the results, the cutting speed was higher as compared to CO_2 laser. Due to higher cutting speed, Fiber laser had high thermal efficiency. There was no significant influence in cut kerf for both the lasers. In fiber laser surface roughness was lower between 0 to 4mm thickness and for higher thickness CO2 laser had good result as compared to fiber laser. [18]

A. Stournaras et al. has investigated experimentally the quality of laser cutting for the aluminum alloy AA5083, with the use of a pulsed CO2 1.8 kW laser cutting system. This work aimed at evaluating processing parameters such as the laser power, the scanning speed, the pulsing frequency and the gas pressure for the laser cutting of aluminum alloys. A statistical analysis of the results has been utilized for determining the contribution of each individual parameter to the cutting quality. . A regression analysis has been used for developing empirical models for the combined effect of laser power, cutting speed, pulsing frequency and assist gas pressure on laser cutting quality. Experimental investigation based on the Taguchi methodology was used for obtaining quantitatively the effect of each process variable. [19]

Avanish Kumar Dubey & Vinod Yadava has presented the optimization of kerf quality during pulsed laser cutting of 8011 aluminium alloy sheet. They had improved kerf quality by optimizing laser parameter such as Gas pressure, Pulse width, Pulse frequency and Cutting speed. They had used pulsed Nd-YAG laser for experiment. [20]

III RESULT

One has reviewed the result of one research paper discussed by Avanish Kumar Dubey & Vinod Yadava based on "Optimization of kerf quality during pulsed laser cutting of 8011 aluminium alloy sheet".

Table 1 – Control factors and their levels used in the experiment for aluminium alloy sheet

Symbol	Factors	Unit	Level 1	Level 2	Level 3
A	Gas pressure	kg/cm^2	4.0	6.0	8.0
B	Pulse width	ms	0.8	1.0	1.2
C	Pulse frequency	Hz	18	23	28
D	Cutting speed	mm/min	7.5	12.5	17.5

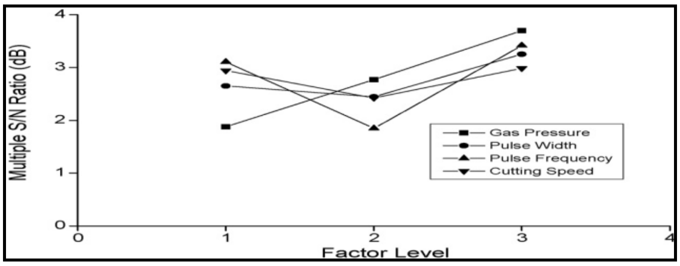

Fig. 4 Effect of factor levels on multiple S/N ratio (0.9mm Al-alloy sheet)

The optimum levels of different control factors for minimum kerf deviation and kerf width obtained are: gas pressure at level 3 (8.0 kg/cm2), pulse width at level 3 (1.2 ms), pulse frequency at level 3 (28 Hz), and cutting speed at level 3 (17.5 mm/min). The graphical representation of factor effect on multiple quality characteristics (*K*d and *K*w) at different levels is shown in Fig. 4. Assist gas pressure and pulse frequency significantly affect the kerf quality in the operating range of process parameters resulted by ANOVA analysis.

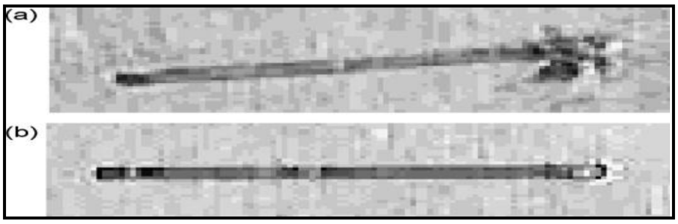

Fig. 5 Scanned view of kerf quality at (a) initial parameter level and (b) optimum parameter level.

IV CONCLUSION

The work presented here is just an overview of previously done researches and future directions of laser cutting process using different optimization techniques. The conclusions drawn over here are discussed below.

(1) Laser cutting process is the most powerful non-traditional process which is used for intricate cuttings, economically and efficiently.

(2) The performance of laser cutting process is mainly depends on number of process parameters like laser power, cutting speed, gas pressure, pulse width, focal length, focal point position etc.

(3) The responses like surface roughness, heat affected zone, kerf width, perpendicularity etc. are achieved at efficient levels using laser cutting process.

(4) From the above literature, it has been reviewed that different optimization techniques were used for optimization of different laser process parameters for different industrial materials.

(5) Main objective of this literature survey is to identify different laser process parameters, performance characteristic, materials and optimization techniques and to find out some research gap for future research work to become beneficial to industry people.

(6) From above literature survey, it has been found that there is some lacking with the use of Grey Relational analysis to optimize fiber laser cutting process parameters of aluminium alloy.

(7) From reviewed result it is shown that assist gas pressure and pulse frequency significantly affects the kerf quality in the operating range of process parameters.

V REFERENCES

[1] http://www.worldoflasers.com/laserhistory.html
[2] http://www.phy.cuhk.edu.hk/phyworld/articles/laser/laser_e.html
[3] Inja Bogdan Allemann & Joely Kaufman, "Laser Principles", 2011, vol 42, pp 7–23.
[4] E-book "Laser Fabrication & Machining of Materials" by Narendra B. Dahotre & Sandip P. Harimkar, Springer, pp 15.
[5] "Laser & its application" by popular science and technology series.
[6] "Fiber Laser Application" developed by OP-TEC: The National Center for Optics and Photonics Education.
[7] A Thesis "LASER CUTTING OF AUSTENITIC STAINLESS STEEL WITH A HIGH QUALITY LASER BEAM" by Catherine Wandera, LAPPEENRANTA University Of Technology, Finland; 2006; pp 23-26.
[8] "Laser cutting, Laserline technical" by Dr. Ing. J. Berkmanns & Dr. Ing. M. Faerber; 2008; pp 4.
[9] Ulas Caydas & Ahmet Hascalik, "Use of the grey relational analysis to determine optimum laser cutting parameters with multi-performance characteristics", journal: Optics & Laser Technology 40 (2008), pp 987–994.
[10] S. Nagesh, H.N. Narasimha Murthy, M.Krishna,& H.Basavaraj, "ParametricstudyofCO2 laser drilling of carbon nano powder/vinylester/glass nano composites using design of experiments and grey relational analysis", journal: Optics & Laser Technology, 48 (2013) pp 480–488.
[11] A.Bharatish , H.N.NarasimhaMurthy , B.Anand , C.D.Madhusoodana , G.S. Praveena , & M.Krishna, "Characterization of hole circularity and heat affected zone in pulsed CO2 laser drilling of alumina ceramics", journal: Optics &Laser Technology, 53(2013) pp 22–32.
[12] T. M. Chenthil Jegan, M. Dev Anand, & R. Ravindran, "Determination of Electro Discharge Machining parameters in AISI202 Stainless Steel using Grey relational analysis", journal: Procedia engineering, vol 38, 2012, pp 4005-4012.
[13] Milos MADIC, Miroslav RADOVANOVIC, Laurentiu SLATINEANU, "Surface Roughness Optimization In CO_2 Laser Cutting By Using Taguchi Method", Vol 75, issue 1, 2013, pp 97-106.
[14] Arindam Ghosal & Alakesh Manna, "Response surface method based optimization of ytterbium fiber laser parameter during machining of Al/Al2O3-MMC", Journal: Optics & Laser Technology, 46 (2013), pp 67–76.

[15] N. Muhammad, D. Whitehead, A. Boor & L. Li, “Comparison of dry and wet fiber laser profile cutting of thin 316L stainless steel tubes for medical device applications”, journal: Materials Processing Technology, 210 (2010), pp 2261–2267.
[16] Hanadi G. Salema, Mohy S. Mansour, Yehya Badr & Wafaa A. Abbas, “CW Nd:YAG laser cutting of ultra low carbon steel thin sheets using O2 assist gas”, journal: materials processing technology, 196 (2008), pp 64–72.
[17] Mayank N Madia & Prof. Dhaval M Patel, “Effect of Focal Length on Surface Roughness of 1mm Thin Brass Sheet”, journal: IJERA, Vol. 3, Issue 5, Sep-Oct 2013, pp.349-352.
[18] S. Stelzera, A.Mahrlea, A. Wetziga, E. Beyera, “Experimental investigations on fusion cutting stainless steel with fiber and CO2 laser beams”, journal: Physics Procedia, 41 (2013) pp 392 – 397.
[19] A. Stournaras, P. Stavropoulos, K. Salonitis, G. Chryssolouris, “An investigation of quality in CO2 laser cutting of aluminum”, journal: Manufacturing Science and Technology, 2 (2009) pp 61–69.
[20] Avanish Kumar Dubey & Vinod Yadava, “Optimization of kerf quality during pulsed laser cutting of aluminium alloy sheet”, journal: materials processing technology, vol 204 (2008) pp 412–418.