Optimization of aluminum alloy by CO₂ laser cutting using genetic algorithm to achieve surface quality

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Abstract. The cutting tool process became one of the uncommon thermal energy-based manufacturing methods used in aerospace and different electronics industries to create complex shapes on different metals and their alloys. This paper presents a genetic algorithm for optimizing wear rate and kerf width mostly during cutting tools of aluminum 6351 CO₂. The experiments were based on the design of Box Behnken, which took into account three laser specifications for cutting process. Control of laser beams, cutting speeds and gas pressure. By reducing the surface roughness and kerf width, the optimum parameters for the laser cutting were determined. Our test results reveal that in solving optimization problems, the suggested genetic algorithm is efficient and efficient and can be incorporated into the intelligent production environment.

1. Introduction

Aluminum alloy Al6351 is widely used in manufacturing industries owing to its inherent properties such as higher strength and high corrosion resistance. Laser cutting is essential to investigate the machining of aluminum alloy because it has many drawbacks. The only downside is that it exhibits high reflectivity in the range of 10.6μm so aluminum alloys are known as hard to cut materials. This reflectivity causes recasting layer that result in the formation of uneven profile resulting in poor surface finish. Another downside is that the use of high power lasers results in a large kerf that will be a big disadvantage in the manufacture of small features and high tolerance parts. CO₂ laser cutting efficiency refers to the combination of control parameters, such as laser beam strength, gas velocity, and cutting speed as well. Therefore, during CO₂ laser cutting, the goal is to minimize the wear rate and kerf size of the aluminum 6351 alloy.[1-3]

Interesting research studies were performed to examine the laser cutting process and it was noticed that many of the researchers focused on consistency characteristics such as tool wear and kerf width. R. Adalarasan et. and. Al. [2015] investigated the effects of CO₂ laser cutting parameters on the kerf width
and surface finish of the aluminum composite. H.A. A.A. From Eltawahni et. Al. [2012] related laser cut parameters associated with stainless steel kerf and roughness.[4-7]

Stournaras et. Al. [2009] examined aluminium alloy laser cutting and found that coupling cutting speed and laser beam power have an effect on the width of the kerf. A. From Riveiro et. Al. [2010] premeditated the effect of CO₂ laser cutting parameters on aluminium-copper alloy content (2024-T3) and found reasonable quality for high power yields [8-10]. Found that the key parameter affecting the width and roughness of the kerf is laser beam power. Milos Madic and Miroslav Radovanovic [2012] found that the Artificial Neural Network (ANN) predicts significantly better surface quality than the Multiple Regression Analysis (MRA) for mild steel cutting by CO₂ laser cutting. In advanced manufacturing, these optimisation techniques are used, but limited applications in the laser cutting process have been documented. This paper focuses on improving surface roughness and kerf width using a genetic algorithm in CO₂ laser cutting of aluminum 6351 to predict the important factors for better quality [11-14].

2. Experimental details

AMADA LCG3015 continuous wave CO₂ laser with maximum power of 3500 Watts was used for machining and for this study aluminum 6351 is chosen as the work material as it is used comprehensively in aerospace, automotive and also in food industry. The sheet dimensions are 350X300 mm with thickness of 2 mm. Figure 1 shows the profile to be cut on the work piece of 3mm thickness. The shape of cut on the work piece allows us to measure the kerf width and roughness in a simple and accurate way. The average roughness was measured along the cut and in the middle of the thickness using 2μm diamond tip Surftest SJ-210 tester and BSPIL – MTR-03003 make tool makers microscope was utilized to measure kerf width of straight cut at 15X magnification [15-18].

2.1 Experimental design

Most of the processing of laser content utilizes the DOE technique. The design of box-behnken lessens the number of trials without any reduction in optimization accuracy. Each experiment study has been designed to be set up with 3 input data and 3 box-behnken levels in order to cover a broader range.
of laser-cut parameters shown in Table 1 showing the variables and their level and table 2 showing the geometry of the box-behnken.[19-22]

| Parameters                     | -1 Level | +1 Level |
|--------------------------------|----------|----------|
| Laser Beam Power (kW)         | 3        | 3.2      |
| Speed (m/min)                 | 5        | 5.4      |
| Gas Pressure (bar)            | 6        | 8        |

Table 1 Specifications and various levels

| Test. No. | Energy (kW) | Time (m/min) | Force (bar) | Robustness (μm) | width (mm) |
|-----------|-------------|--------------|-------------|-----------------|------------|
| 1         | 3.2         | 7.2          | 8           | 2.367           | 0.255      |
| 2         | 3.1         | 7.2          | 7           | 2.508           | 0.308      |
| 3         | 3.1         | 7.4          | 6           | 2.381           | 0.268      |
| 4         | 3.2         | 7.0          | 7           | 2.528           | 0.325      |
| 5         | 3.1         | 7.2          | 7           | 2.539           | 0.306      |
| 6         | 3.1         | 7.0          | 6           | 2.670           | 0.342      |
| 7         | 3.2         | 7.4          | 7           | 2.329           | 0.246      |
| 8         | 3.1         | 7.2          | 7           | 2.546           | 0.302      |
| 9         | 3.0         | 7.2          | 6           | 2.442           | 0.266      |
| 10        | 3.1         | 7.4          | 8           | 2.438           | 0.277      |
| 11        | 3.1         | 7.2          | 7           | 2.528           | 0.310      |
| 12        | 3.0         | 7.0          | 7           | 2.501           | 0.298      |
| 13        | 3.0         | 7.2          | 8           | 2.385           | 0.260      |
| 14        | 3.1         | 7.2          | 7           | 2.490           | 0.301      |
| 15        | 3.0         | 7.4          | 7           | 2.327           | 0.270      |
| 16        | 3.2         | 7.2          | 6           | 2.383           | 0.282      |
| 17        | 3.1         | 7.0          | 8           | 2.546           | 0.327      |

Table 2 Box-behnken design

3. Results and discussion

3.1. Response surface methodology

| Responses               | Surface Roughness | Kerf Width |
|-------------------------|-------------------|------------|
| Model (p value)         | < 0.0001          | < 0.0001   |
| Significant model terms | B, BC, A²         | B, AB, A², B², C² |
| F Value                 | 29.65             | 48.63      |
| Lack of Fit             | 0.5035            | 3.05       |
| R-Squared               | 0.9744            | 0.9843     |
| Adj R²                  | 0.9416            | 0.9640     |
| Adeq Precision          | 13.093            | 24.336     |

Table 3. ANOVA Table for surface roughness and kerf width

Table 3 is the ANOVA table for the surface roughness and kerf width. For all the responses, the p-value is < 0.05, lack of fit value is > 0.05 and sufficient accuracy value is > 4 suggest that this model can be used to traverse the design space. In addition, all responses have a R squared (R²) value of > 0.9
and the modified R squared values are closer to the R squared value, which indicates an excellent agreement between the expected and the actual results.[23-26].

3.2. Optimization using Genetic algorithm

Genetic algorithm is one of the optimization techniques of soft computing that are commonly used to obtain optimal solutions for parameters of the machining method to fulfil the objective function set.[27-31]

The objective function is

Minimize

Ra (P, S, p)
Kw (P, S, p)

Subject to the constraints: 3.0 ≤ P ≤ 3.2, 7.0 ≤ S ≤ 7.4, 6 ≤ p ≤ 8

where P, S, p are laser cutting control parameters as input and Ra and Kw represent the surface roughness and kerf width as output.

GA algorithm

Process 1. The objective function is minimization and select cross over and mutation operator.

The population size is 100, cross over probability pc is 0.8 and mutation probability pm is 0.1.

Process 2. In the defined population, evaluate each string.

Process 3. Terminate if t is greater than t max or other termination criterion is satisfied.

Process 4. In the defined populations, perform reproduction.

Process 5. In the random pairs of strings, perform crossover.

Process 6. In the defined population on every string, perform mutation

Process 7. Estimate each string in the new population, Set t = t+1 and the go to step 3.

Optimum parameters

| S. No. | Control levels | GA Expected values (Input) | Answers | GA Expected values (responses) |
|-------|----------------|----------------------------|---------|-------------------------------|
| 1     | Energy (kW)    | 3.20                       | Surface Robustness(µm) | 2.334                         |
| 2     | Time (m/min)   | 7.39                       | Kerf width mm          | 0.245                         |
| 3     | Force (Bar)    | 7.70                       |                      |                               |

Table 4. Optimum levels

4. Conclusion

In present work, optimization of the surface roughness and kerf width has been carried out using genetic algorithm for CO2 laser cutting of aluminium6351 sheet of 3mm thickness. Following
conclusions were made can be drawn on the basis of the obtained results:
(i) Results of genetic algorithm specifies that minimum surface roughness and kerf width for aluminium 6351 sheet of 3 mm thickness can be achieved by operating with input parameter setting of laser beam power = 3.2 kW, cutting speed = 7.39 m/min, gas pressure = 7.7 bar.
(ii) Cutting speed significantly affects the surface roughness and kerf width in the operating range of parameters.
(iii) The optimum surface roughness and kerf width were 2.334 μm and 0.245mm respectively.

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