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Experimental investigation on laser micro-machining of Al 7075 Al

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ABSTRACT

Light metal alloys have low density, high stiffness and high strength to weight ratio. These alloys are of great importance in engineering industries for construction of transportation equipment, aircraft parts, aerospace, military & missile application, etc. Nowadays, aluminium alloys are becoming the world's second and most used material after steel. In this present research work, Al 7075 alloy sheet of 2 mm thickness has been micro-machined of square shape by using Nd:YVO4 pulsed laser of maximum capacity of 9.4 W with spot beam diameter of 50 μm, laser pulse width of 4.2 ns and wavelength of 1.064 nm. The machining quality in terms of kerf width, HAZ and surface roughness are observed at different parametric combination of the influencing parameters, namely laser beam power, pulse frequency and scanning speed. Taguchi methodology (L9 OA) is utilized for the design of experiment. The responses are also optimized and analyzed by Taguchi methodology. The experimental results are then verified and justified the significance of the processing parameters following ANOVA and confirmation experiment. The confirmation test shows the improvement of the responses over all the experimental result. SEM has also been observed for microstructure study.

1. Introduction

Aluminium and its alloys are the most versatile and acceptable engineering materials because of their unique characteristics such as high strength-to-weight ratio, more resistance to corrosion, high thermal and electrical conductivity, non-toxicity and ease of formability & machinability. There are specific applications of recently developed Al 7075 alloys; like aircraft fittings, aerospace, missile parts, defense equipments, etc. Machining of complex shapes with minimum feature size and finishing standard of these alloys is found to be difficult using conventional machining processes. Applications of laser beam in modern industries are increasing at a fast pace due to their ability to cut very hard as well as soft materials, electrically conductive as well as non-conductive materials, such as HSS, super alloys, ceramics, composites, diamond, plastics and rubber [1]. One of the main objectives of laser machining is to observe and minimize the HAZ. Araújo et al. [2] observed heat affected zone (HAZ) extension in CO_2 laser cutting of 2024 aluminum alloy. Stournaras et al. [3] investigated experimentally the quality of laser cutting for the aluminum alloy AA5083 of 2 mm thickness with the use of a pulsed CO_2 1.8 kW laser. The quality of the cut has been monitored by measuring kerf width, edge roughness and size of the HAZ by evaluating laser power, scanning speed, frequency and gas pressure. Dubey et al. [4] optimized two kerf qualities such as kerf deviation and kerf width simultaneously using Taguchi quality loss function during pulsed Nd:YAG laser beam cutting of aluminium alloy sheet of 0.9 mm-thick. Sharma et al. [5] presented the modeling and optimization of cut quality characteristics i.e. kerf deviation (Da) and kerf taper (Ta) during Nd:YAG laser cutting of aluminum alloy thin sheet along the curved profile. The input process parameters are identified as arc radius of curve profile, oxygen pressure, pulse width, pulse frequency and cutting speed. Riveiro et al. [6] observed influence of processing parameters and optimal conditions of edge surface aspect, dross characteristics and HAZ for CO_2 laser cutting of aluminium–copper alloy (2024-T3). Laser processing is suitable for geometrically complex profile cutting, drilling, marking and making miniature holes. Kardas et al. [7] carried out experimental investigation on laser cutting of rectangular geometry in 2024 aluminum sheet under high pressure nitrogen assisting gas to investigate temperature and thermal stress fields. Yilbas et al. [8,9] carried out laser cutting of a triangular geometry into aluminum 2024 alloy for analyzing thermal stress field. Leone et al. [10] investigated experimentally the kerf geometry laser in cutting of 6061-T6 aluminium alloy sheets by means of a 150 W multimode pulsed Nd:YAG laser. Sharma et al. [11] presented modeling and optimization of cut quality in terms of kerf taper (Ta) and surface roughness (Ra) during pulsed Nd:YAG laser cutting of thin Al-alloy sheet for straight profile. Dubey et al. [12]

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studied on finding the optimal parameters by using robust design and quality optimization tool for cutting of a reflective sheet made of 8011 aluminium alloy with a 200 W pulsed Nd:YAG laser beam with oxygen assist gas. A considerable improvement in the kerf taper (KT) and material removal rate (MRR) has been found. Mandal et al. [13] investigated on micro-drilling of copper sheet of 0.2 mm thickness by Nd:YVO_4 laser. Hole taper has been investigated with respect to the laser beam power, pulse frequency, scanning speed and number of passes. Khettabi et al. [14] presented comparison between aluminum alloys and titanium alloy laser machining. Chen et al [15] studied the characteristics of the temperature at cut front edge (Tce) during fiber laser cutting of AA2219 aluminum alloy. Wang et al [16] drilled aluminum and copper films with femto second double-pulse laser. The drilling process is monitored by recording the light transmitted through the sample, and the morphology of the drilled holes is analyzed by optical microscopy. Md. Antar [17] investigated high speed hole drilling (0.8 mm dia) of nickel based aerospace alloy (5–10 mm thick) with the state-of-the-art EDM and laser drilling machines. Results showed a step change in drilling speed (4–5 folds) compared to previous generations of laser machines (ND:YAG laser and standard EDM drill), with significant enhancement in hole quality and integrity.

Researchers have explored less number of LBM process for cutting, drilling, marking and micromachining of different light metal alloys like 2024-T3, AA5083, Al6061, specially Al7075, etc. As a result, the research carried out so far is highly inadequate to complete the database of machinability and further research is necessary to study the effect of various process parameters on different machining criteria to fulfill the potential of the light metal alloys in industries. In this paper Al 7075 alloy is micro-machined of square geometry by using Nd:YVO_4 pulsed laser of maximum capacity 9.4 W. L9 orthogonal array is utilized for design of experiment following Taguchi methodology. Experimental results are analyzed in respect of S/N ratio plots. ANOVA as well as confirmation test has also been performed to justify the adequacy of the optimum solution. A considerable improvement in kerf quality has been achieved.

2. Experimental planning

2.1. Workpiece material selection

From the past research it is observed that Al 2024 alloy has been experimentally tested by more number of researchers. Whereas, Al 7075 alloy has been studied in less number of cases. So in this present research work, Al 7075 alloy has been chosen as the work material. At first, Al 7075 was developed in secret by a Japanese company, Sumitomo Metal, in 1943 and was eventually used for airframe production in the Imperial Japanese Navy. Al 7075 has been sold under various trade names including Zicral, Ergal, and Fortal Constructal. The chemical composition of Al 7075 alloy, tested on the sample used for this research work, is given in Table 1.

Table 1
Chemical composition of 7075 Al alloy.

Alloying element	Percentage
Aluminium	89.79
Zinc	5.66
Magnesium	2.15
Copper	1.32
Silicon	0.35
Iron	0.45
Manganese	0.08
Titanium	0.05
Chromium	0.10
Others	0.05

Al 7075 alloy is strong enough and comparable to many steels, has a density of 2.810 g/cm^3, good fatigue strength but average machinability, and has less resistance to corrosion. It is produced in many tempers, some of which are 7075-0, 7075-T6, 7075-T651, 7075-T7. The mechanical properties of 7075 Al alloy depend greatly on the temper of the material which is shown in Table 2. These properties can change depending on the form of material used. Thicker plate may exhibit lower strengths and lower elongation than the thinner one.

Al 7075 alloy was purchased in block form. With the help of wire-cut electric discharge machine, sheets of 250 mm × 25 mm × 2.5 mm is cut. Due to rough surface it is then polished to make it scratch-free as much as possible. Polishing of the sized work piece has been made by smooth and uniform directional abrading of the surface of interest with the help of emery paper of grade 120 followed by 220. Before experiment, the job is cleaned by acetone solution and dried-up.

2.2. Experimental set-up

Nd:YVO_4 laser is utilized for the experimental purpose i.e. for laser micro-cutting operation. In this laser, the parameters which can be varied are laser power, pulse frequency, scanning speed and repeat factor (repetition rate i.e. how many times a set of experimental condition is applied for a single observation. Thus, number of pass will be 1+ repetition rate) which may influence the machining characteristics (responses). However as the micro-machining is concern, repetition rate is considered as the fixed parameter. Fig. 1 shows a typical solid state, Nd:YVO_4laser (Model: EMS 100) of maximum laser beam power 9.4 W, wavelength of 1064 nm with spot beam diameter of 50 μm and laser pulse width of 4.2 ns. The laser system has three main parts i.e. laser unit, control unit interfaced with a computer and work station. The laser unit consists of EMS 100 laser marker compatible with Scorpion Rapid and Raptor Laser. The control unit consists of OFF/ON switch, device for setting/adjusting the process parameters through computer. The workstation is used for placing and aligning the workpiece.

2.3. Selection of process parameter:

For the present work, three influencing parameters i.e. laser beam power (L B P), pulse frequency (P F) and scanning speed (S S) with three levels each are selected to observe the effect on responses i.e. kerf width, HAZ and surface roughness in micro-cutting operation of Al 7075 alloy. Ranges of process parameters are set through the pilot/trial experiment. Trial experiment was done by varying a parameter keeping other parameters fixed at same value. So workable range for that parameter can be selected. The same procedure was repeated for the remaining parameters. Ranges of the (influencing) process parameters are shown in Table 3.

Once the ranges of influencing parameters are selected, L9 Orthogonal Array [18,19] following the Taguchi's methodology

Table 2
Mechanical properties of 7075 Al alloy.

Temper type of Al 7075	Maximum tensile strength (MPa)	Maximum yield strength (MPa)	Elongation (%)
7075–0	280	140	9–10
7075-T6	510–540	430–480	5–11
7075-T651	570	500	3–9
7075-T7	505	435	13