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Optimization of kerf quality characteristics during Nd: YAG laser cutting of nickel based superalloy sheet for straight and curved cut profiles

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ABSTRACT

Kerf characteristics are important from the quality of cut point of view. The kerf characteristics are also changing with the profile of cutting. This paper presents parameter optimization of the kerf quality characteristics during pulsed Nd: YAG laser cutting of nickel based superalloy thin sheet. The kerf quality characteristics considered are kerf width, kerf taper and kerf deviation, and measured through Tool Makers Microscope. The essential process input parameters were identified as oxygen pressure, pulse width, pulse frequency and cutting speed. Based on the Taguchi quality design concept, an L_{27} orthogonal array has been used for conducting the experiments for both straight and curved cut profiles. The results indicated that the optimum input parameter levels suggested for curved cut profiles are entirely different from straight cut profiles except kerf width.

1. Introduction

Superalloys are used for manufacturing those components which are required to retain their shape at elevated temperature. Superalloys are mainly of three types: iron based, cobalt based and nickel based. The latter being best suited for aeroengine applications. Nickel based superalloy sheets in general and SUPERNI 718 sheet in particular are used as casing for jet engines, aeroengine turbine blades, turbo charger and pump body parts. Due to the improved mechanical properties of nickel based Superalloy sheet complex profile cutting is difficult by the conventional sheet cutting operations. Advanced sheetmetal cutting processes (ASCPs) are well suited for cutting advanced difficult-to-cut sheetmetals. Laser beam cutting (LBC) is one of the ASCP, which is widely used for cutting any complex profiles in the sheet of any known engineering materials on the earth. The material to be cut may be fragile, brittle, electric conductors or non-electric conductors, hard or soft [1].

LBC, being a non-contact process, does not involve any mechanical cutting forces and tool wear. LBC is a thermal energy based cutting process, which is executed by moving a focused laser beam on the surface of the workpiece with appropriate scanning speed (Fig. 1). Oxygen gas is also supplied through a nozzle to remove the molten metal. LBC of sheetmetals has always been a major research area for getting the exceptionally good quality of cut. Due to converging–diverging shape of laser beam profile a kerf taper (K_t) always exist in cut sheet specimens [1]. Also, resolidified layers, adhesion of dross and heat affected zone (HAZ) are major problems for achieving better quality cuts. There are many input parameters affecting the quality of laser cutting such as laser type and power, type and pressure of assist gas, cutting speed, sheet material composition and its thickness, and mode of operation of laser beam (Continuous or Pulsed mode). To achieve acceptable level of kerf quality characteristics, it is necessary to choose optimum combination of input process parameters. Researchers have experimentally studied the kerf quality characteristics like K_w or K_t during LBC and concluded that these qualities can be optimized by proper control of input process parameters [2]. A lot of experimental and theoretical investigations have been performed to analyze the effect of process parameters on cut geometry and cut surface quality. Some researchers have applied design of experiments (DOE) techniques to analyze and optimize the laser cutting parameters [2–4,6–14].

Li et al. [3] applied Taguchi's matrix method to study the kerf width, depth of cut and HAZ during laser cutting of QFN (quad flat no-lead) packages using a diode pumped solid state laser system where input process parameters are lamp current, pulse repetition rate and cutting speed. Their findings for QFN package laser cutting quality are dependent on laser frequency, cutting speed and laser driving current. Lim et al. [4] applied the Taguchi method for studying the surface roughness obtained during high speed laser cutting of stainless steel sheets with process parameters such as cutting speed, laser power and assist gas

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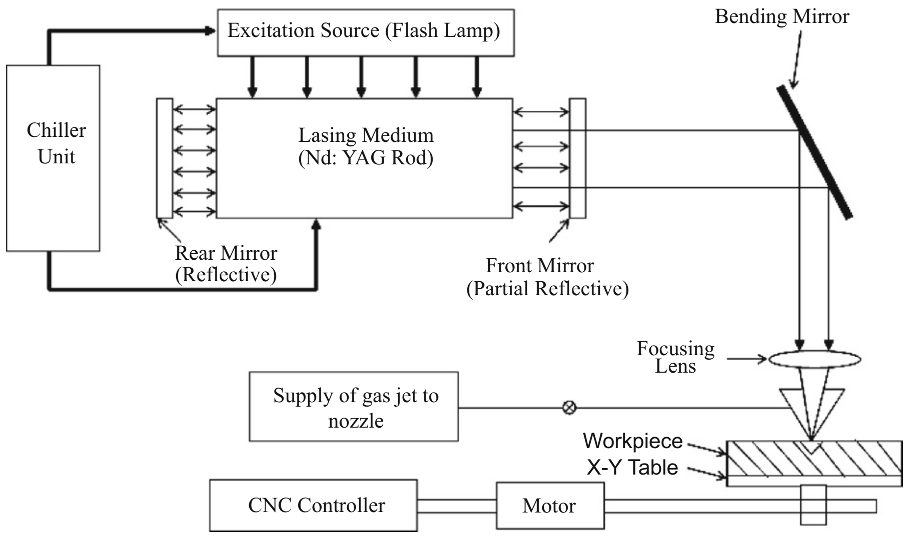

Fig. 1. Nd: YAG laser beam cutting machine.

pressure. Chien and Hou [5] applied the Taguchi methodology (TM) for investigating the recast layer formed during the laser trepan drilling of Inconel 718. They found that recast layer is generally thicker at the entrance end of the drilled hole than any other point along the depth of the hole. Mathew et al. [6] performed parametric studies on pulsed Nd: YAG laser cutting of fibre reinforced plastic composite sheet of 2 mm thick. Kuar et al. [7] found the optimum value of lamp current, pulse frequency and cutting speed for minimum surface roughness during pulsed Nd: YAG laser cutting of silicon nitride ceramics. Almedia et al. [8] applied the factorial design approach to determine the effects of pulse energy, overlapping rate and type of assist gas on the surface roughness and dross formation during Nd: YAG laser cutting of pure titanium and titanium alloy. Quintero et al. [9] studied the effect of parameters on HAZ, during cutting of ceramic composites. Dubey and Yadava [10–12] applied orthogonal array with principle component analysis as well as TM with response surface methodology (RSM) to optimize multiple quality characteristics during pulsed Nd: YAG laser cutting thin sheets. Some researchers have also tried to solve the problem with multiple quality characteristics by the grey relational analysis. Their findings show that quality characteristics can be improved with DOE applications. Caydas and Hascalik [13] have applied the Taguchi Methodology with grey relational analysis to determine the optimum laser cutting parameters with multi-performance characteristics. Rao and Yadava [14] have studied the effects of parameters on Kerf width, kerf taper and kerf deviation simultaneously during laser cutting of straight and curved profiles using the hybrid approach of the Taguchi methodology and grey relational analysis and the weights of the quality characteristics are determined by employing the entropy measurement method.

Researchers have investigated the effect of laser cutting parameters on performance of laser cut quality and also suggested the optimal parameter ranges during cutting of sheetmetals. Few researchers have also applied the DOE approach for deciding the optimal parameter levels during study of LBC process performance. Most of the experimental investigations so far and researchers have considered the straight cut for analyzing the laser cut quality. Very few research works are available in the literature showing selection of optimum parameter levels for different cut profiles. Further study is required for finding the interesting results for different cut profiles, i.e. straight and curved cut profiles.

In this paper, three kerf quality parameters such as K_w, K_d, and K_t have been optimized individually during pulsed Nd: YAG LBC of nickel based superalloy sheet using the Taguchi methodology. The control factors taken are: oxygen pressure, pulse width, pulse frequency and cutting speed. The sheet material is nickel based superalloy SUPERNI 718 (an equivalent grade to Inconel 718) and its thickness is 0.7 mm. Based on the Taguchi quality design concept, an L_{27} orthogonal array has been used for conducting the experiments. These results are then used for optimization. Further, analysis of variance (ANOVA) based on mean data and S/N ratio has been used to determine the percentage contribution of each input parameters on K_w, K_t and K_d for both straight as well as curved cut profile. The results of straight cut optimized values have also been compared with curved cut optimized values.

2. Taguchi's methodology for parameter design

The process parameter design using TM is an important tool for robust design of process parameters. It offers a simple and systematic approach of design for performance, quality and cost. The Taguchi method has been proven to be a reliable means of evaluating several design parameters simultaneously, and is highly effective in reducing the number of experiments required. According to Taguchi "The effect of uncontrollable factors can be nullified by appropriate selection of level combinations of controllable factors or process parameters" [15]. The Taguchi methodology (TM) for robust design is a unique statistical experimental design technique, which greatly improves the engineering productivity. According to the Taguchi approach the machining process must be operated at optimum levels with minimum variation in its functional characteristics. Functional characteristics of manufacturing process output parameters are affected by controllable factors as well as uncontrollable factors. Uncontrollable factors and their effects on process performance can be nullified by applying appropriate level of input parameters [15,16].

2.1. Selection of orthogonal array

In TM the experiments are performed as per specially designed experimental matrix known as Orthogonal Array (OA). OA is a special matrix in which entries are at various levels of input parameters, and each row represents individual treatment