

Study on Fiber Laser Beam Machining by Using Mild Steel

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Abstract

In today's rapidly changing the scenario in manufacturing industries, the metal cutting processes are essential for a manufacturing unit to respond effectively to severe competitiveness and increasing demand for the quality product in the market. Laser Beam Cutting (LBC) is one of the most widely used manufacturing technique for generation of accurate and complex shape geometrical shape on ferrous metal, nonferrous metal, stone plastic and ceramic component with high dimensional accuracy. Fiber laser are solid state laser technologies that offer a combination of high beam quality and a wave length that is easily absorbed by metal surface. This work aim to evaluate the optimization laser beam cutting parameter for 10 mm thickness of mild steel sheets by using fiber laser beam machine of 1000 W power and Nitrogen as assist gas. Focus of work mainly on output response parameter like Material Removal Rate (MRR), Kerf Width (KW), Kerf Deviation (KD), Surface roughness. Results are analyzed using analysis of variance (ANOVA) technique. The effect of different input process parameter like feed rate, laser power, frequency and gas pressure is studied on the output response.

Keywords: *Material Removal Rate (MRR), Kerf Width (KW), Kerf Deviation (KD), Surface roughness.*

I. INTRODUCTION

1.1 Introduction to Non Traditional Processes

Advanced industries like automobiles, turbines, missiles, nuclear reactor etc. requires materials like high strength

temperature resistance allows which have high strength toughness, corrosion resistance and other various properties. With rapid development in the field of materials, it has become essential to develop cutting tool materials and processes which can be safely and conveniently machine such new materials for productivity, high accuracy. Consequentially non-traditional techniques of machining are providing effective solution to the problem imposed by increasing demand for high strength temperature resistant alloys, which otherwise was very difficult to machine with conventional methods. The processes are non-conventional in the sense that they do not use conventional tool for machining purpose. Instead these utilize energy indirectly to remove material from work piece. These techniques can be classified in to three categories, i.e. mechanical electro thermal electro chemical machining processes.

1.2 Laser Beam Machine (LBM)

The name LASER is an acronym for “Light Amplification by the Stimulated Emission of Radiation”. There are two main types that have been used in most of all applications are the Carbon Dioxide (CO₂) laser and Oxygen (O₂). Laser cutting, in general, is an effective way to

reduce production and manufacturing costs. This is due to the advantages of high production rate as well as the fact that lasers can be mechanized, computer controlled and integrated into assembly lines. Many industries have been revolutionized by the application of laser equipment in their production lines. This is because of the high quality and low distortion characteristics of the cutting action which can be achieved.

1.3 History About Laser Beam

Kelvin Planck given the concept of quanta in 1900 and in 1920 it was well accepted that apart from wave like characteristics of light it also shows particle nature while interacting with matter and exchange energy in the form of photons. The initial foundation of LASER theory was laid by Einstein who has given the concept of stimulated emission in 1917, though the first industrial LASER for experimentation was developed around 1960s. Towns and Shaw low (1957) produced the first LASER called as Ruby LASER.

1.4 Spontaneous Emission

The electron moves from lower energy level to high energy level. On reaching the higher energy level, the electron reaches an unstable energy band. And it comes

back to its ground state within a very small time by releasing a photon. This is called as spontaneous emission.

Fig. shows the absorption of photon by an electron.

1.5 Stimulated Emission

In a material, if more number of electron can somehow pumped to the higher meta-

stable energy state as compare to number of atom at ground state, and then it is called population inversion. Such electron at metastable state, can return to the ground state in the form of avalanche provided stimulated by a photon of suitable frequency or energy this is called as stimulated emission. Shown in fig.

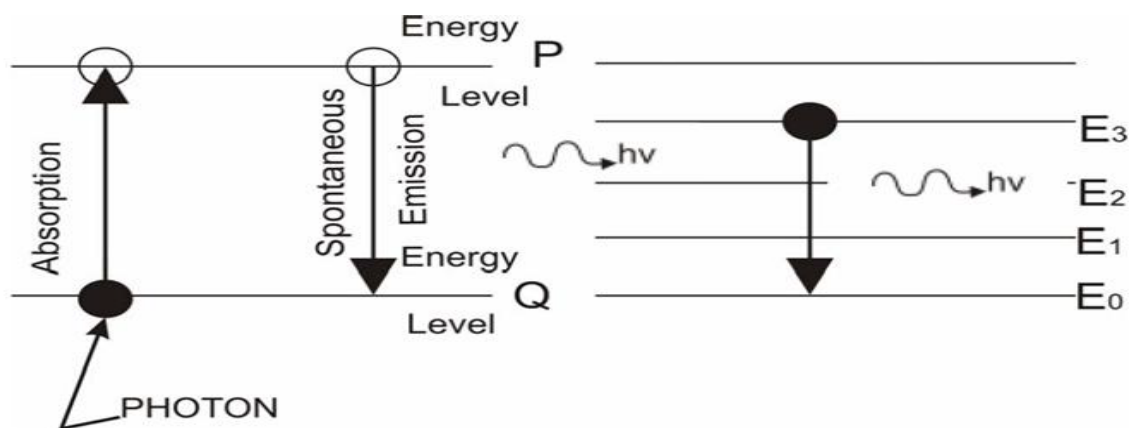


Fig. 1.1 Energy bands in materials

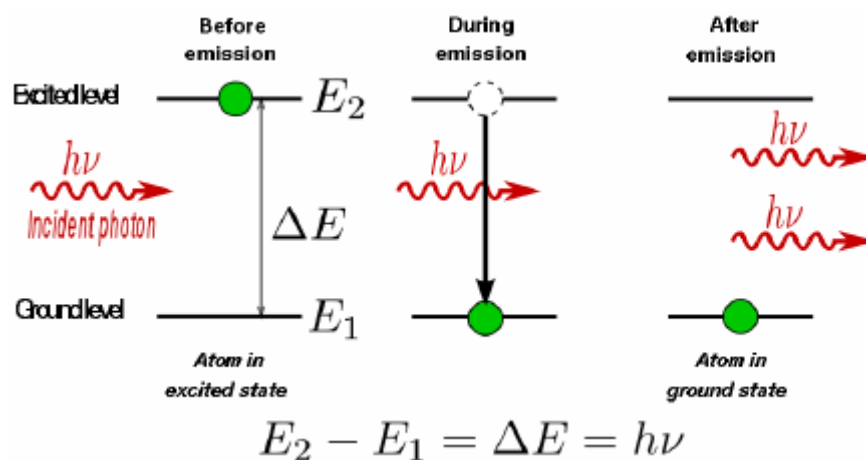


Fig. 1.2 Stimulated emissions

1.6 Cutting Principle

The basic principle of LASER beam cutting is shown in fig. An optical lens placed in the path of LASER beam is used to focused the beam and to create a focal length suitable for the cutting application the distance between the lens and material is adjusted so that the focal point of the LESER beam is concentrated on or below the surface of the material depending upon the material process required. Material around the beam will melt and is blown away by the assist cutting gas that is concentric to the LASER beam.

The mechanism of material removing during LBM includes different stages melting, vaporization, chemical degradation. When a high density LASER beam is focused on work surface thermal energy is absorbed which heat and transforms work volume in to a molten.

Vaporized or chemically changed state that can easy removed by flow of high pressure assist gas jet, which accelerate the transform material end eject it from machine zone LASER beam cutting is a thermal process.

1.7 Types Of Laser

Many materials can use as heart of LASER. Depending on the lensing medium LASERS are classified as:

- i. Gas lasers
- ii. Solid state lasers
- iii. Fiber lasers
- iv. Chemical lasers
- v. Excimer lasers
- vi. Semiconductor lasers
- vii. Dye lasers

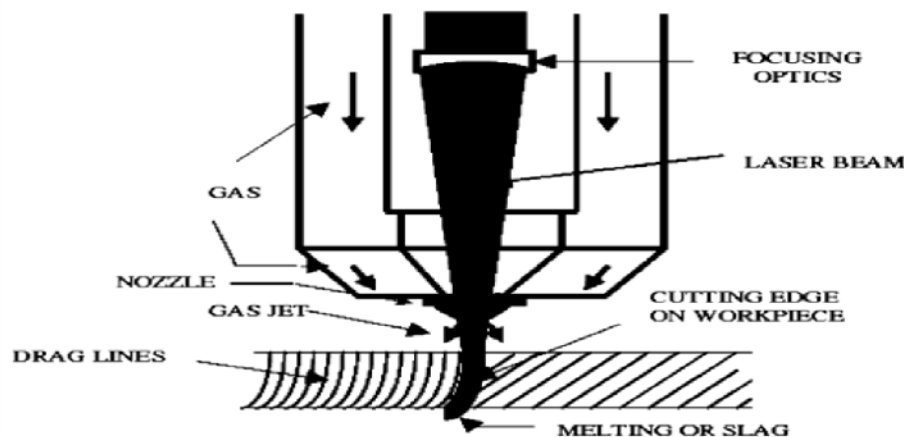


Fig. 1.3 Cutting principle

1.8 Process Parameters

1.8.1 Continuous wave (CW) or Pulsed laser operations

The highest cutting speeds can be obtained at high power level in continuous wave mode operation. Continuous wave means that the laser power output is constant without interruption over time.

1.8.2 Laser power and intensity

Laser power is the total energy emitted in the form of laser light per second. The intensity of laser beam is equal to its power divided by area over which the power is concentrated. The high intensity causes the material to heat up rapidly so that little time is available for heat to dissipate in to the surrounded material. This produces the high cutting rate and an excellent quality of cut.

1.8.3 Cutting speed or feed rate

In the laser cutting processes, the cutting speed or feed rate is an also important parameter which decides the heat input in the cutting front and interaction time of laser beam and work piece.

1.8.4 Focal length of the lens

The focal length of lens defines the shape of the focused laser beam. A lens with the short focal length produce a small spot size and short depth of focus, generally

resulting in high speed and good cutting quality of thin sheet metal. However, care full control of distance between the lens and work piece is necessary. When thicker materials are cut, the depth of focus must be adopted to the material thickness by selecting the longer focal length. As the longer focal length also results in greater focal spot power, it must be increase in order to maintain intensity and cutting speed.

1.8.5 Wave length of laser beam

Absorption in the material being cut is dependent upon the wave length of the laser beam

1.8.6 Laser beam mode

A laser beam mode refers to distribution of energy through its cross section. The mode affected the cutting process, because its affects the size of the focused spot and the intensity of the focused beam and also its affects intensity distribution in the beam and focus and, as a results, cut quality a good mode is therefore essential in laser cutting.

1.8.7 Nozzle size and stand of distance

Gas assistance is essential in laser cutting. Therefore, nozzle geometry and standoff distance are important. Nozzle design and flow dynamic through the nozzle differ

substantially from other thermal cutting processes. This is mainly due to the compactness and diameter of the nozzle, which is always larger than the kerf produced below it. As a result, only a portion of the gap jet formed by the nozzle penetrates the kerf. Nozzle standoff distance depends on the design of nozzle.

1.8.8 Gas type and gas pressure

The cutting gas used is crucial to the cutting result. Oxygen generally yields good cutting performance in carbon steel and low alloy steel. However, oxygen reacts with the base metal, and the cut edge is covered with oxide layer. These are the reasons why high alloy steels are being cut with nitrogen more and more often whenever sufficient laser power is available.

1.9 Response Variables

1.9.1 Surface roughness

Surface roughness is the unevenness or irregularity of the surface profile and is measured as the mean height of the profile, R_z , or as an integral of the absolute value of the roughness profile, R_a .

The mean height of the profile, R_z , is used in quality classification.

1.9.2 Heat affected zone

The thermal heat of laser cutting produces the heat affected zone next to the cut edge. The heat affected zone is the part of the material whose metallurgical structure is affected by heat but is not melted.

1.9.3 Kerf width

Kerf is a groove or a slit or a notch usually the lower and upper part of the cut is usually not parallel, it will be narrow at the bottom than the top. Kerf width is measured along the whole cut line of the width. It is the difference of starting width of the top profile to the ending width of the top profile. This same applies to the bottom surface.

1.9.4 Kerf deviation

The kerf deviation (K_d) is the difference of maximum and minimum width of top kerf measured along the length of cut.

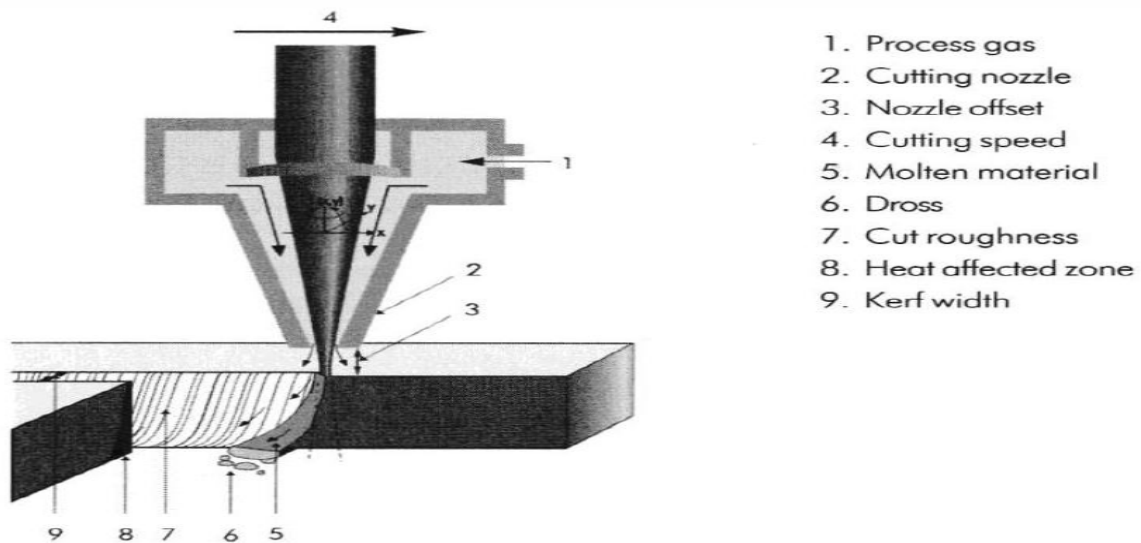


Fig. 1.4 LASER cut important surface characteristics

2.1 Applications

- Automotive: welding transmission components, welding a sheet metal, cutting hydro formed parts.
- Computer: spot welding annealing, silicon cutting
- Aerospace: welding aluminum and titanium cutting aerospace components
- Medical device: marking, cutting, spot welding

2.2 Advantages

- Reduction of total work time
- Increase in production quality

- LASER cutting is precise, clean and silent
- Capability of cutting coated or surface treated materials

2.3 Limitations

- High initial capital cost
- High maintenance cost
- Presence of heat affected zone- specially in gas assist co2 LASER cutting.
- Thermal process not suitable for heat sensitive materials like aluminum, glass, fiber.

2. LITERATURE REVIEW

Rajaram et. Al. 2003 conducted experiment on sample of 4130 steel with CO2 LASER cutting system and the

combined effects of power and feed rate on kerf width, surface roughness, striation frequency and heat affected zone have been studied. Regression analysis was used to developed model that described the effect of the independent process parameters on LASER cut quality.

Yilbas (2004) examined LASER gas assisted cutting process and statistical method based on factorial analysis was introduces to identify the influence of cutting parameter on the resulting cut quality. international standard for thermal cutting were employed to identify the measurable variables when assessing the cutting quality.

Karatas et al. (2006) conducted experiments on CO2 LASER for cutting of steel and influence of beam waist position relative to the work piece surface and the work piece thickness on the striation formation was examined. The kerf width was modeled using a lump parameter analysis.

Sobih et al. (2008) presented the results of LASER cutting study using a 1Kw single mode fiber LASER, a relative newcomer in the field of LASER metal cutting. Striation free LASER cut was

demonstrated when cutting 1mm thick mild steel sheets.

Powell et al. (2011) presented the result of an experimental and theoretical investigation in to the phenomenon of striation free cutting', which is the feature of fiber laser or oxygen cutting of thin section mild steel. It was concluded by the author that the lowest roughness mild steel cut edges are produced at intermediate speeds considerably lower than the maximum cutting speed.

2.1 Literature Summary

Form the study of research paper on LASER beam machining, it is found that different kinds of LASER beams have been used with different operating characteristics for improving MRR, kerf width , surface finish striation affect etc. and different modification are done for improving machining characteristics and this are found to be beneficial. Same are as:

- i. Certain micro parts are produced with enhanced machining quality and roughness by thermos chemical machining.
- ii. Work has been done to reduce thermal stress produced in work

material during cutting of material by using dual CO2 LASER beam machining.

- iii. MRR depend upon different type of LASER beam machining equipment used with different operating characteristic.
- iv. Quality of drilled material of LCD glass by LBM can be increased when done under water than that of done in air.
- v. Optimization of continuous wave CO2 LASER parameter have been done for maximum penetration and minimum heat input, width of heat affected zone in weldment.
- vi. Cutting speed of continuous wave ND: YAG LASER is found to be more than that of pulsed wave for cutting bare and coated metal plates.
- vii. Slow speed cutting causes on change in magnetic properties for average power of 100W but magnetic flux density is found to be changed.

- viii. On machine measurement positioning of work piece three dimensionally is done to prevent it from misalignment and deformation.

2.2 Research Gap

Some gaps are identified on the basis of which aim for further study has been decided.

Following some gaps are mentioned:

- i. It has been seen that insufficient work has been done for optimization of fiber LASER beam parameters for certain material.
- ii. Surface finish enhancement needs to be done.
- iii. Most of the literature available in this area shows that researchers have concentrated on single quality characteristics as objectives during optimization of LBM.

3. DESIGN OF STUDY AND EXPERIMENTATION

3.1 Introduction To Methodology

In this section, methodology to do the work is explained in detail. Design of Experiment (DOE) technique will be used.

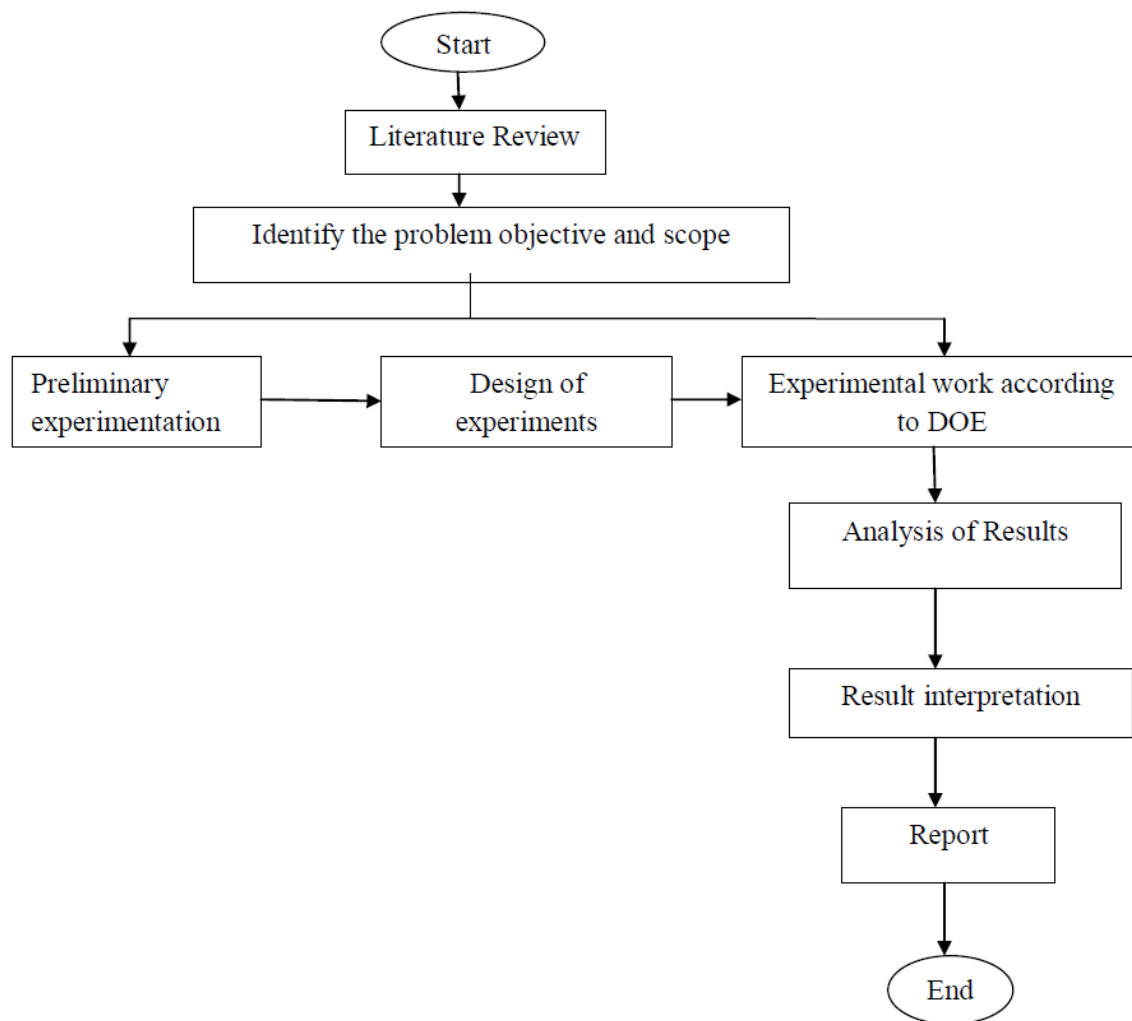


Fig 3.1 Flow chart of the experimentation

3.2 Design Of Experimentation (DOE)

Design of experiment involves designing a set of experiments, in which all relevant factors are varied systematically. When the results of these experiments are analyzed, they help to identify optimal condition, the factors that most influenced the results, and those that do not, as well as detail such as the existence of interaction and synergies between factors. DOE methods required well-structured data matrices. When applied to a well-

structured matrix, analysis of various delivers accurate results, even when the matrix that is analyzed is quite small. Experiments design is a strategy to gather empirical knowledge, i.e. knowledge based on the analysis of experimental data and not on theoretical models. It can be applied whenever you intend to investigate a phenomenon in order to gain understanding or improve performance.

Design of experiments is widely used in research and development, where a large proportion of the resources go towards solving optimization problems. The key to minimizing optimization cost is to conduct as few experiments as possible. DOE required only a small set of experiments and thus help to reduce costs.

3.2.1 Introduction to Taguchi method

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affected the mean and variance of process performance characteristics that defined how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to

determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there are an immediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

3.2.1.1 Orthogonal arrays

Taguchi's orthogonal arrays are highly fractional designs, used to estimate main effects using only a few experiments runs. These designs are not only applicable to two level factorial experiments, but also can investigate main effects when factors have more than two levels. An orthogonal array is a type of experiment where the columns for the independent variable are orthogonal to one another. The Taguchi arrays can be derived or looked up. Small arrays can be drawn out manually; large arrays can be derived from deterministic algorithms. Generally, the arrays are selected by the number of parameters (variable) and the number of levels (states).

Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameters values to optimize the performance characteristics. The data from the arrays

can be analyzed by plotting the data and performing ANOVA.

3.2.1.2 Taguchi Method Design Of Experiments

The general steps involved in the Taguchi method are as follows:

- i. Define process objective, or more specifically, a target value for the performance measure of the process. This may be a flow rate, temperature, etc. the target of a process may also be a minimum or maximum.
- ii. Determine the design parameter affecting the process. Parameter are variable within the process that affect the performance measure such as temperature, pressure, etc. that can be easily controlled. The number of levels that the parameter should be varied at must be specified.
- iii. Create orthogonal array for the parameter design indicating the number of and condition for each experiment. The selection of orthogonal array is based on the number of parameter and the level of variation for each parameter.

- iv. Conduct the experiments indicated in the complete array to collect data on the effect on the performance measure.
- v. Complete data analysis to determine the effect of the different parameters on the performance measure.

3.3 Objective Function

The objective of the study is to evaluate the main effect of LASER power, feed rate, frequency and gas pressure on material removal rate (MRR), kerf Width (Kw) and Kerf Deviation (KD). MRR was calculated using formula, KW and KD was measured by using profile projector equipment.

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