EXPERIMENTAL INVESTIGATION OF LASER CUTTING PROCESS PARAMETERS

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ABSTRACT

Laser cutting is radiant energy based unconventional machining process used to cut complicated shapes in harder materials. The objective of this project is to investigate and optimize the process parameters associated with Nd:YAG laser cutting of Mild steel, Stainless steel 304 and Stainless steel 316L. In this project, we used Nd:YAG LASER for cutting the materials because of availability and high efficiency. The experiment was designed and carried out to find the surface hardness and surface roughness of the materials which is cut by CNC laser cutting machine. In this project, we altered the parameters like the laser input power and cutting speed and analyzed the output parameters. The result showed that the parameters like power and cutting speed have major impact over surface roughness and surface hardness.

Keywords*: Nd:YAG Laser, cutting speed,laser input power.*

1.INTRODUCTION

A Laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The term "laser" originated as an acronym for "**Light Amplification by Stimulated Emission of Radiation**". The first laser was built in 1960 by Theodore H. Maiman at Hughes Research Laboratories, based on theoretical work by Charles Hard Townes and Arthur Leonard Schawlow. A laser differs from other sources of light in that it emits light coherently. Spatial coherence allows a laser to be focused to a tight spot, enabling applications such as laser cutting and lithography.

1.1 Nd:YAG Laser:

Nd:YAG (neodymium-doped yttrium aluminum garnet; Nd:$Y_3Al_5O_{12}$) is a crystal that is used as a lasing medium for solid-state lasers. The dopant, triply ionized neodymium, Nd(III), typically replaces a small fraction (1%) of the yttrium ions in the host crystal structure of the yttrium aluminum garnet (YAG), since the two ions are of similar size. It is the neodymium ion which provides the lasing activity in the crystal, in the same fashion as red chromium ion in ruby lasers.

Nd:YAG lasers are optically pumped using a flashtube or laser diodes. These are one of the most common types of laser, and are used for many different applications. Nd:YAG lasers typically emit light with a wavelength of 1064 nm, in the infrared. However, there are also transitions near 946, 1120, 1320, and 1440 nm. Nd:YAG lasers operate in both pulsed and continuous mode. Pulsed Nd:YAG lasers are typically operated in the so-called Q-switching mode: An optical switch is inserted in the laser cavity waiting for a maximum population inversion in the neodymium ions before it opens.In this Q-switched mode, output powers of 250 megawatts and pulse durations of 10 to 25 nanoseconds have been achieved. The high-intensity pulses may be efficiently frequency doubled to generate laser light at 532 nm, or higher harmonics at 355, 266 and 213 nm.

Nd:YAG absorbs mostly in the bands between 730–760 nm and 790–820 nm. At low current densities krypton flash lamps have higher output in those bands than do the more common xenon lamps, which produce more light at around 900 nm. The former are therefore more efficient for pumping Nd:YAG lasers.

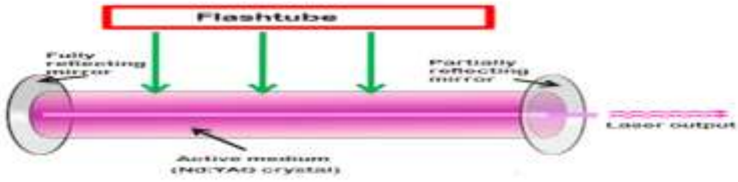

Fig 1.1 Schematic Diagram Of Nd:YAG Laser.

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The Properties of Nd:YAG at 25 °C (with 1% Nd doping) are

- Formula: $Y_3Al_5O_{12.}$
- Crystal structure: cubic.
- Mass Density: 4.56 g/cm³.
- Young's Modulus: 280Gpa.
- Melting point: 1970ºc..
- Tensile Strength: 200 MPA

ADVANTAGES:

1.It is very useful for thin materials for quick processing.
2.It offers high DPI capabilities.
3.It is also useful for applications which need high power density such as metal marking.
4.It offers higher energy output and very high repetition rate.
5.It is very easy to attain population inversion.

APPLICATION:

1. It is used in ophthalmology to correctposterior capsular opacification.

2. It can also be used for flow visualization techniques in fluid dynamics.

3. It is most commonly used in laser range finders and laser designators.

4. It is used as pumping tunable visible light lasers.

1.2 Rockwell Hardness Testing Machine:

Rockwell Hardness is probably the most used hardness testing method because it is simple and self contained, so that there is no need for a separate microscope reading.

Fig 1.2 Rockwell Hardness Testing Machine

PRINCIPLE:

Rockwell & Rockwell Superficial tests consists of forcing an indentor (Diamond or Ball) into the surface of a test piece in two steps i.e. first with preliminary test force and thereafter with additional test force and then measuring depth of indentation after removal of additional test force (Remaining preliminary test force active) for measurement of hardness value.

WORKING:

In case of 'RASN' series machines for Rockwell or Rockwell Superficial Test a preliminary test force in first applied & then indicator is automatically set for zero. Quickly thereafter & additional test force is applied without removing the preliminary test force. When the penetration is stabilized, the additional test force is removed & the hardness number is shown directly on the indicator.

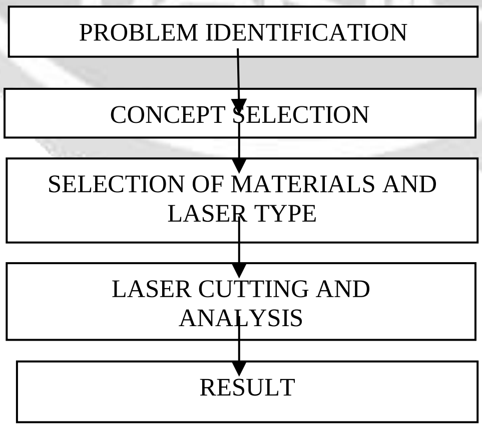
1.3 Surface Roughness Tester:

This Surface Roughness Tester is small in size, light in weight, easy to carry. Although complex and advanced, it is convenient to use and operate.Surface roughness tester in the measurement of workpiece surface roughness, the first sensor placed on the workpiece surface to be measured, and then start the instrument for measurement, driven by the instrument within the precision drive mechanism along the measured surface to do constant speed linear taxiway.

Fig 1.3 Surface Roughness Tester.

Through the built-in sharp stylus to feel the roughness of the surface to be measured, the roughness of the surface of the workpiece to be measured at this time will cause the stylus to be displaced. This displacement causes the inductance of the sensor inductor to change, The end produces an analog signal proportional to the measured surface roughness, the signal after amplification and level conversion into the data acquisition system, the DSP chip digital filtering and parameter calculation of the collected data, the measurement results are given on the display, and also Can be output on the printer, but also with the PC to communicate.

2. METHODOLOGY:



2.1 Mild Steel:

Mild steel (iron containing a small percentage of carbon, strong and tough but not readily tempered), also known as plain-carbon steel and low-carbon steel, is now the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Mild steel contains approximately 0.05–0.25% carbon making it malleable and ductile. Mild steel has a relatively low tensile strength, but it is cheap and easy to form; surface hardness can be increased through carburizing.

In applications where large cross-sections are used to minimize deflection, failure by yield is not a risk so low-carbon steels are the best choice, for example as structural steel. The density of mild steel is approximately 7.85 g/cm³and the Young's modulus is 200 GPa.

Low-carbon steels suffer from yield-point run out where the material has two yield points. The first yield point is higher than the second and the yield drops dramatically after the upper yield point. If a low-carbon steel is only stressed to some point between the upper and lower yield point then the surface develops Lüder bands. Low-carbon steels contain less carbon than other steels and are easier to cold-form, making them easier to handle.

The chemical composition of mild steel:

- Maximum percentage of Carbon is 0.25 - 0.290
- Maximum percentage of Manganese is 1.03
- Maximum percentage of Phosphorus is 0.040
- Maximum percentage of Sulphur is 0.050
- Maximum percentage of Silicon is 0.280
- Maximum percentage of Manganese is 1.03

PROPERTIES:

- Tensile Strength, Ultimate: 400 - 550 MPa
- Tensile Strength, Yield: 250 MPa
- Elongation at Break (in 200 mm): 20.0 %
- Elongation at Break (in 50 mm): 23.0 %
- Modulus of Elasticity: 200 GPa
- Bulk Modulus (typical for steel): 140 GPa

ADVANTAGES:

1. Very strong and flexible
2. Maintains its strength indefinitely
3. Versatile
4. Can be recycled
5. Mild Steel is ductile and can easily be machined
6. Mild Steel has high toughness and high strength than Stainless Steel
7. No need to change the tool repeatedly and no special tools are required for machining.

APPLICATIONS:

1. It is used in bolted, riveted or welded construction of bridges, buildings and oil rigs.
2. It is used in forming tanks, bins, bearing plates, fixtures, rings, templates, jigs, sprockets, cams, gears, base plates, forgings, ornamental works, stakes, brackets, automotive and agricultural equipment, frames, machinery parts.
3. It is used for various parts obtained by flame cutting such as in parking garages, walkways, boat landing ramps and trenches

2.2 Stainless Steel 304:

Stainless steel 304 is the standard "18/8" stainless; it is the most versatile and most widely used stainless steel, available in a wider range of products, forms and finishes than any other. It has excellent forming and welding characteristics. The balanced austenitic structure of Grade 304 enables it to be severely deep drawn without intermediate annealing, which has made this grade dominant in the manufacture of drawn stainless parts such as sinks, hollow-ware and saucepans. For these applications it is common to use special "304DDQ" (Deep Drawing Quality) variants. Grade 304 is readily brake or roll formed into a variety of components for applications in the industrial, architectural, and transportation fields. Grade 304 also has outstanding welding characteristics. Post-weld annealing is not required when welding thin sections.

The chemical composition of stainless steel 304:

- Maximum percentage of Carbon is 0.03
- Maximum percentage of Manganese is 2.0
- Maximum percentage of Phosphorus is 0.045
- Maximum percentage of Sulphur is 0.030
- Percentage of Molybdenum is indicated between 2.0 to 2.5
- Maximum percentage of Silicon is 0.75
- Maximum percentage of Nickel is 0.10
- Maximum percentage of Chromium is 20 whereas minimum percentage of Chromium is 18.

PROPERTIES:

- Density: 8.00g/cm3
- Electrical resistivity: 0.072 x 10-6 Ω.m

- Specific Heat: 0.50 kJ/kg-K (0–100 degrees Celsius)
- Thermal conductivity: 16.2 W/m.K (100 degrees Celsius)
- Modulus of Elasticity : 193 GPa
- Melting Range: 1,450 degree.

ADVANTAGES:

1. Excellent hot and cold forming process and performance
2. Better low temperature performance
3. Has good weldability.

APPLICATIONS:

1. Sinks and splashbacks
2. Saucepans
3. Cutlery and flatware
4. Architectural panelling
5. Sanitaryware and troughs
6. Tubing
7. Brewery, dairy, food and pharmaceutical production equipment.

2.3 Stainless Steel 316L:

316L is the low carbon version of 316 Stainless Steel. It does not precipitate due to carbide at grain boundary i.e. it is immune from sensitization. Thus it is heavily utilized in welded components of higher thickness more than 0.2 inches. The austenitic structure also offers these stainless steel grades incredible toughness, even down to extreme lower temperatures such as −150 Centigrades(−238 °F) to absolute zero (−460 °F).

316L, as the name suggests, has lower carbon content in it as compared with its parent type 316 stainless steel. Although 316L has lower carbon content, 316L is very much alike to 316 in most of the applications. Interestingly the cost of both the types are also similar, and both are long lasting, corrosion resistant, and best selection for stress intensive applications. 316L, on the other hand, is a better selection for an application that needs a lot of welding because 316L is less susceptible to weld decay.
The chemical composition of stainless steel 316L:

- Maximum percentage of Carbon is 0.03
- Maximum percentage of Manganese is 2.0
- Maximum percentage of Phosphorus is 0.045
- Maximum percentage of Sulphur is 0.03
- Percentage of Molybdenum is indicated between 2.0 to 2.5
- Maximum percentage of Silicon is 1.0

2.4 Working Principle:

Laser cutting is a technology that uses a laser to cut materials, and is typically used for industrial manufacturing applications, but is also starting to be used by schools, small businesses, and hobbyists. Laser cutting works by directing the output of a high-power laser most commonly through optics.The laser optics and CNC (computer numerical control) are used to direct the material or the laser beam generated. A typical commercial laser for cutting materials involved a motion control system to follow a CNC or G-code of the pattern to be cut onto the material. The focused laser beam is directed at the material, which then either melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high-quality surface finish.

Generation of the laser beam involves stimulating a lasing material by electrical discharges or lamps within a closed container. As the lasing material is stimulated, the beam is reflected internally by means of a partial mirror, until it achieves sufficient energy to escape as a stream of monochromatic coherent light.

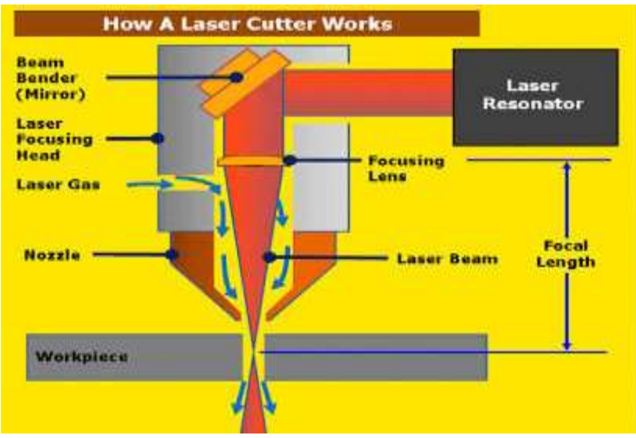


Fig 2.1 working Of Laser Cutting Machine.

Mirrors or fiber optics are typically used to direct the coherent light to a lens, which focuses the light at the work zone. The narrowest part of the focused beam is generally less than 0.0125 inches (0.32 mm). in diameter. Depending upon material thickness, kerf widths as small as 0.004 inches (0.10 mm) are possible. In order to be able to start cutting from somewhere other than the edge, a pierce is done before every cut.

Laser cutting for metals has the advantages over plasma cutting of being more precise and using less energy when cutting sheet metal; however, most industrial lasers cannot cut through the greater metal thickness that plasma can. Newer laser machines operating at higher power are approaching plasma machines in their ability to cut through thick materials, but the capital cost of such machines is much higher than that of plasma cutting machines capable of cutting thick materials like steel plate.

2.5 2D Diagram Of Profile Cutting:

Fig 2.2 2D Diagram OfProfileCutting.

2.6 3D Diagram Of Profile Cutting:

Fig 2.3 3D Diagram Of Profile Cutting.

2.7DESIGN OF EXPERIMENTS:

TRIAL	INPUT			OUTPUT	
A	Speed(mm/min)	Power(W)	Thickness (mm)	Roughness (µm)	Hardness (RHB)

1	1200	800	4	1.725	67
2	1000	900	5	5.916	75
3	800	1000	6	6.653	91
4	1150	800	4	3.498	73
5	950	900	5	7.524	76
6	750	1000	6	11.088	93
7	1250	800	4	2.726	71
8	1050	900	5	8.231	74
9	850	1000	6	8.453	94

The above table represents the surface roughness and surface hardness values for mild steel material.
Table 4.1 Test for Mild Steel**.**

TRIAL	**INPUT**			**OUTPUT**	
B	**Speed(mm/min)**	**Power(W)**	**Thickness (mm)**	**Roughness (µm)**	**Hardness (RHB)**
1	1200	800	4	6.362	95
2	1000	900	5	7.569	82
3	800	1000	6	6.899	84
4	1150	800	4	4.517	97
5	950	900	5	5.443	86

6	750	1000	6	5.768	81
7	1250	800	4	5.889	94
8	1050	900	5	6.038	86
9	850	1000	6	5.052	81

The above table represents the surface roughness and surfacehardness for the Stainless steel 304 material.
Table 4.2 Test for Stainless Steel 304**.**

TRIAL	**INPUT**			**OUTPUT**	
C	**Speed(mm/min)**	**Power(W)**	**Thickness (mm)**	**Roughness (µm)**	**Hardness (RHB)**
1	1200	800	4	5.886	94
2	1000	900	5	4.735	79
3	800	1000	6	5.090	84
4	1150	800	4	5.098	94
5	950	900	5	5.220	81
6	750	1000	6	5.030	86
7	1250	800	4	5.783	95
8	1050	900	5	5.622	81
9	850	1000	6	4.364	84

The above table explains the surface roughness and surface hardness for the Stainless steel 316L material.
TABLE 4.3 Test for Stainless Steel 316L**.**

3.RESULTS AND DISCUSSION

SURFACE ROUGHNESS:

MATERIAL	CUTTING SPEED	INPUT POWER	SURFACE ROUGHNESS
1.MILD STEEL			
For 4mm	- 1200	800	1.725
For 5mm	- 1000	900	5.916
For 6mm	- 800	1000	6.653
2.STAINLESS STEEL 304			
For 4mm	- 1150	800	4.517
For 5mm	- 1050	900	6.032
For 6mm	- 850	1000	5.052
3.STAINLESS STEEL 316L			
For 4mm	- 1150	800	5.098
For 5mm	- 1000	900	4.735
For 6mm	- 850	1000	4.364

SURFACE HARDNESS:

MATERIAL	CUTTING SPEED	INPUT POWER	SURFACE HARDNESS
1.MILD STEEL			
For 4mm	- 1150	800	73
For 5mm	- 950	900	76
For 6mm	- 750	1000	94
2.STAINLESS STEEL 304			
For 4mm	- 1150	800	97
For 5mm	- 1050	900	87
For 6mm	- 800	1000	84
3.STAINLESS STEEL 316L			
For 4mm	- 1250	800	95
For 5mm	- 1050	900	82
For 6mm	- 750	1000	87

4.CONCLUSION:

The solution to the given task was to find reserves in the use of laser cutting machines.Series of experiments were performed in which the cutting parameters have been optimized for most grades of the processed materials and thicknesses.In this project,surface roughness and surface hardness of the materials were found out for the various cutting speeds and laser input power.We conclude that the material has minimum surface roughness and maximum surface hardness at specific cutting speeds and laser input power.

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