Research & Reviews: Journal of Material Sciences
DOI: 10.4172/2321-6212.1000234
e-ISSN: 2321-6212
p-ISSN: 2347-2278

A Review: Effect of Different Laser Types on Material Engraving Process

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Research Article

Received: 27/08/2018
Accepted: 29/10/2018
Published: 06/11/2018

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Keywords: Laser engraving, Process parameter, Surface roughness, Engraving depth, Engraving.

ABSTRACT

The laser is a non-traditional device used in many applications because it is a versatile flexibility and cost-effective. In this paper, different laser types of engraving different material were discussed for different fundamental researchers on laser engraving. Laser engraving is very practical to engrave hard and various material by removing part of layer from the surface to a specific depth. The effect of laser parameters such as wavelength, pulse duration, repetition-rate and mode of operation has studied various types of material. Also, the effect of material properties such as optical and physical properties with respect to incident laser radiation was studied. There are many kinds of industrial laser which are used for engraving like, carbon dioxide (CO_2) laser, Neodymium-doped Yttrium Aluminum Garnet (Nd: YAG) laser, fiber laser and others. This review discussed the effect of three types of laser engraving on different material. With a sample comparison explains a summary of each author and the type of laser, material with the result and their application speed.

INTRODUCTION

The laser is a versatile technology that has the required flexibility for processing a wide range of materials for various applications, such as cutting, welding, drilling, engraving, rapid Manufacturing, ablation and another application like medical, communications, military, etc. [1-3]. Their importance comes from its wide advantage like, contact-less with the machine, high accuracy, a low heat-affected zone, high-speed, flexibility, versatility and easy automation and computer control, In addition to little processing times and less cost [4,5].

LITERATURE REVIEW

The present works will be focused on the engraving process for its widely uses. Where around 90% of industrial laser engraving is done for product identification in industries including domestic goods, microelectronics, automotive and aerospace the remainder being for aesthetic applications such as decorative patterns and company logos [5]. Also, the security marking was developed and growth due to decrease the marking scales which were done using short wavelength lasers [6]. Laser engraving is a surface process, where the focused laser beam is converted into heat energy on the substrate and leads to remove a part of the layer from the surface to a specific depth [4,7]. This technique was very practical and complex, although a specified computer program should be used to control the laser head. Despite this complexity, very accurate, complex form and clean engraving could obtain from this technique. Also, it has some advantages like no need skilled craftsmanship, little time cost to engrave a lot of pieces and engraving different type of material in the same machine [7,8]. The engraving process importance came from it wide application such as Printing, Micromachining, vase marking, graphic, design, Engraving on jewelry and intaglio printing (e.g., banknotes and passports). There are many types of industrial laser used for engraving process, the most popular used laser and that will be reviewed in this work was, carbon dioxide CO_2, Neodymium-doped Yttrium Aluminum Garnet Nd: YAG laser and fiber laser. During the engraving process, the laser beam varying the optical appearance of the surface at the point where the laser beam hits the substrate. At this point, the heating, melting and vaporization phenomena were taking place to remove layers from the material surface to investigate the engraving process. Vector scans or raster scan are used to scan the laser beam for engraving the object in two dimensions [4]. There are three techniques for engraving with the laser, the first mask technology **(Figure 1)**, second Vector technique **(Figure 2)** and in dot-matrix printing [1,9]:

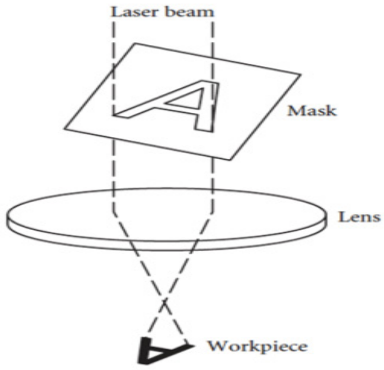

Figure 1: Mask engraving technology.

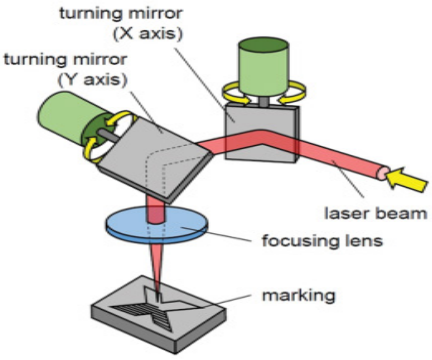

Figure 2: Vector technique.

The degree of precision of the shape, the removal rate and the surface quality during the engraving process strictly depend on the material properties (absorption, reflection, transmission, melting point and another), the laser source characteristics (wavelength, power, speed, spot size and another) and the process parameters (surface roughness, depth of engraving and another). Also, there are different optimization method used to design the experiment and organize the effect of laser parameters like full factorial design, Taguchi, Gray relation analysis, and ANOVA method. There are many previous studies that touched on the laser engraving process and dealt with from different side will be reviewed here. Some of the studies that have been used with reference to the most prominent features. We would like to point out that the studies that we will review have come at different time periods and included a number of countries as a sign of their importance and continued to work and develop them. In the end, a simple comparison was made between all researchers which discussed the laser type, materials, results and the application or benefit of each study. This paper will Classify the engraving process depending on the laser type CO_2, Nd: YAK, Fiber lasers and the effect of each laser will be discussed for different material using different authors experiment in different years.

Carbon Dioxide CO_2 Laser

The CO_2 laser was one of the most powerful and important gas lasers that have been invented by Kumar Patel of Bell Labs in 1964. The industrial power used for this laser ranges between10-10000 W with a wavelength 10.6 mm and can a band centering 9-4 mm [10]. For this type of laser, there are many parameters that affected on the engraving process like, wavelength, laser mode (CW or Pulse), scanning speed, cooling type, spot size and other parameters that will remember for the different research experiment. The CO_2 laser is generally (but not always) the most appropriate source for organic materials such as paper, wood and some polymers containing additives [6]. It was one of the most practical lasers used for this reason some research has been done to enhance or investigates its effect. Other research invented a method for engraving different material and different technique.

Donald G et al. invented a method for engraving photopolymer printing plates using a 1200 watt, carbon dioxide CO_2 laser to provide an economical method with high quality. In their work, the engraving process was done through several stages [11]. Firstly, the photopolymer plate surface was treated, and then the release layer was removed. After that, the laser was used for engraving the top surface of the material finally the scraps that appear after laser engraving was removed. A computer system with the specific CAD software was used as a control unit which sends a data during engraving operation for scanning the material surface. From their invention, they printed on photopolymer without using a graphic art film or photographic masks with high quality engraved photopolymer plates and they use laser engraving with a traditional process. In addition to, this process has a disadvantage which was the residue appeared after this process and its need multistage that reduces the quality of working time.

e-ISSN: 2321-6212
p-ISSN: 2347-2278

Bebghalem et al. studied the effect of CO_2 laser parameters on engraving the glass [9]. They used optical and ordinary glass to engrave a measurement scales for measuring apparatus about 1/10 µm of precision. A CO_2 laser with 25 W maximum power was used in their experiment. The parameter which has been used in this process is laser scanning speed (400, 600, 800, 1000 m/s), the power (25, 75 and 80% of 25 W) and the number of passes (one, two and three passes). The laser beam was guided to the substrate by galvanometric heads which consist of two fixed mirrors. These two mirror direct the laser beam to the lens which focuses the beam at the workplace. They also made a calibration between the sample marked by laser and reference sample. The calibration results showed good exactitude and a weak dispersion in reading value. However, they notice some cracks in the engraved sample due to the number of passage which makes a defect in their work. In the present work, some authors use underwater techniques for reducing the heat in the sample which produce crack and another defect.

Ashraf and Fauzan investigated the effect of laser parameter on the characteristic of the engraving and the width size using traditional CO_2 laser engraving machine on 304-grade stainless steel [12]. In their work engraving was done on 304 grades stainless steel using eight tests include eight parameters combination. The process parameter which discussed in this study includes assisting gas, gas pressure, cutting speed, focal height and focusing lens. The metallurgical microscope was used to test and measure the sample. The design of experiments, the analysis was used for analyzing the quantitative results employing Minitab. They found that the engraving width was greatly affected by cutting speed and the interaction between power and speed. The qualitative analysis has been shown various characteristic differences, in spite of using the same parameter combination. From their study, they found that engraving characteristic of width size could be predicted from the parameters used when using the traditional CO_2 laser machine. The defects of this work were in using fewer of the experiment so that their results are not enough to be dependence. In addition to, there are many other important parameters of laser which affected the engraving process they don't study it.

Wangui et al. studies the influence of beam orientation in engraving using the CO_2 laser. They discussed the different uses of the laser, and the challenges in using sealed off, continuous CO_2 laser in the engraving process with the different incident angle of the beam [13]. In their work, a 60 W continuous CO_2 laser was used and the movable mirrors and lend which work like delivery systems that guide the laser waves to the workpieces. The process was done on Perspex and soda lime glass. Different speed and different angle of the incident was used for engraving the material. A projector and analyzed were used for measuring the depth and width, also the roughness of engraving was measured by the profilometer. From their result, they found that, by increasing the incident angle the kerf width increase and the engraving depth decrease. Also, both the kerf width and engraving depth becomes larger in engraving at a lower speed more than in engraving at high-speed. This process offers several benefits including high quality, engraving many materials and small marking. However, their experiments don't depend on any design of experiment for arranging the experiment so it adds the same weaken for their work.

Aichinger and et al. investigated and improved a flatbed laser engraving and cutting. Since flatbed laser engravers and cutters are widely used in industry for graphics and design branches [14]. For this reason, the processing of unwanted image effects or deformation became important. That's why a leading technology company worked to know these mistakes and identify the reasons and disposal. In their investigation, the MatLab model has been used for controlling the laser parameters, movement and substance data. The sealed off CO_2 laser type has been used for engraving with power ranged from 25 to 80 watts. They get improvement by regulation of the software. The performance was advanced using newer and more intelligent algorithms so that the output quality was improved by using complex error corrections of the hardware (motion saucer, laser source). Their work was new and they get a good result, but their method was complex and defect and need a professional programmer to work on it.

Genna et al. has experimentally investigated the laser processing on poly-methyl-. Methacrylate (PMMA) sheet. The tests were done by carving pockets of 10 × 10 mm^2 on the surface of PMMA plate, with a thickness of 3 mm, using a 30 W CO_2 laser source, continuous (CW) working or pulse (PW) [15]. The aim of their work was to focus the points on processing parameter and how it effects on the high of etching in the machined volume, the removed layer and the roughness of the surface. They used a galvanometric mirror to move the laser beam and the 100 mm focal length lens "flat field" to have 200 µ focused spot. The PC control system was used which permits the era of the geometric examples and the Setting of the Emulating methodology parameters: the average power (Pa), the pulse frequency, the scan speed and the wave mode: CW or PW. After testing the engraved plate, their results showed that the wave mode was not affected by the removal rate and the roughness. But, they are affected by changing the scanning speed where it decreases with increasing the scanning speed and increases it by changing the wave mode from CW to PW at 15 kHz to pulsed-wave at 2 kHz. The advantage of this work was machining with a fine accuracy and less effort. The defect of this work was the result was tacking for one value of power and they don't use the design of the experiment.

Jiang et al. developed a textile design method combining laser engraving and foil lamination was explored [16]. With the foil laminating, the surface of denim fabric shows shinning effect. After that, the foil-laminated denim samples were treated with laser engraving by adjusting the parameters, including resolution (dots per inch, dpi) at 20, 30, 40 and 50 dpi and the pixel time (microsecond, Is) at 120 and 180 Is to melt and evaporate the aluminum foil and some surface fibers. The properties of the laser-engraved foil-laminated denim fabric, including weight, tearing strength, air resistance, surface observation, color appearance, colorfastness and abrasion resistance, and some low-stress mechanical properties, were investigated. The experimental results revealed that the changes in these properties are mainly related to the melted and evaporated surface laminated aluminum foil

e-ISSN: 2321-6212
p-ISSN: 2347-2278
DOI: 10.4172/2321-6212.1000234

and different sizes of cracks, wrinkles, and pores formed on the fiber surface with the increment of laser energy applied. Their study also revealed the potential of pattern creation with different values and reflective appearance for the embellishment of denim fabric combining the aluminum foil laminating method through the laser engraving process. With lower resolutions, engraved vague patterns with small laser beam dots could be achieved. While the treatment resolution increased, clear patterns could be performed. Based on the same resolution, the higher the pixel time can export more energy, which makes the pattern look more clearly. Their design approach opens up new possibilities for metallic denim fabric design without any chemicals used. In addition to their benefits, the defect in this process was its reduce the tearing strength of fabrics which reduce the using age of fabric.

Neodymium-Doped Yttrium Aluminum Garnet Nd: Yag Laser

The Nd: YAG laser it was one type of solid-state laser which was commonly used in a different application. The Yttrium Aluminum Garnet (YAG) crystal is a host lattice of this laser which has Y3Al5O12 as chemical composition. This laser can be operated with continuous (CW) or in pulsed mode, depending on pumping method. A xenon with medium pressure (500-1500 Torr) or a krypton with high pressure (4-6 atm) is used as a flash lamp to pump this laser. The output power of a CW mode for this laser was ranged from 150 W to 6 kW, and in Q-switched pulsed mode, reach to 50 MW with 20 ps pulse duration and 1-100 Hz repetition rate. In addition, diode pumping was used for high output power (up to 6 kW). Nd: YAG lasers have many Applications like laser surgery and materials processing, for example, welding, cutting, drilling, and surface modification and many more [3]. This laser has many parameters that effect on the engraving process like frequency, repetition rate, power and other parameters for material and material response all will be discussed in different work of many researchers in different years.

A Q-switched Nd: YAG laser has been used for marking process stainless steel. The marking process was controlled using a special computer program to design and make the characters [17]. There are different process parameters that affect laser marking: pulse frequency, electric current, scanning speed, but the pulse frequency has a significant effect on this process. In their work, they study the relation between the quality of marking and pulse frequency of the laser. The effect of pulse frequency on mark depth and width were measured using an optical microscope and electron microscope. The marked contrast was measured using an image-analysis system with a frame-grabber card and a charge-coupled-device (CCD). They have been discovered that the mark depth, width and mark contrast depend on the interaction between laser radiation and the material, which is significantly affected by pulse frequency. Their results showed that the mark quality was highly affected by the pulse frequency. They have been found that the mark depth reaches its maximum value at 3 KHz pulse frequency while the width kept constant with varying the pulse frequency value. Also, the evaporation of material decrease with increasing the pulse frequency as well the oxidization becomes significant that led to improvements in the marked contrast. The maximum mark contrast has been found at 8 KHz of laser pulse frequency. The advantage of this study was in their application on metals material which was difficult in manufacturing.

Bereczki et al. developed a technique to produce a three-dimensional surface on a hard steel material using a Q-switched Nd: YAG laser engraving system with a scanning head by ablation a layer from the substrate. They developed a computational method for curves level ablation and it is suitable filling within the laser system [18]. They have been studied laser parameters taking into the account the material removal rate, level of detail and finishing of surfaces. A hard surface was produced by studying the kind of machined steel and used thermal treatment. A special software for laser drawing has been used to import the appropriate document for the level bends additionally laser handling parameters have been improved to make the engraving. The MATLAB programs have been used to generate the numerical process by directing micro-machining the substrate which obtained a grayscale bitmap at the output. The ablation process has been seen with linear behavior. An optical refining with an ultrasound device was applied after the laser removal to decrease the rigidity of the surface that brought about surfaces with specular reflection. In the end, the CW laser mode was used for controlling the melting generated on the surface. This strategy brought about a variable, quick and economical process. The Fresnel lens array injected utilizing the form made in this examination worked properly showing the practicality of the technique proposed. Besides their benefit in three dimensions engraving with few files, this process needs a professional programmer.

Leone et al. investigated the effect of engraving process on a different type of wood using a Q-switched diode-pumped Nd: YAG green laser with a wavelength 532 nm [19]. This laser has pulse duration, reach to 150 ns, up to 35 kHz pulse repetition frequency with 5 W maximum mean powers and about 80 μm diameters of focused beams. They examined many parameters like, the average power which depended on pulse frequency, the speed of the beam and a number of scanning or repetitions of the laser. A PC was used for controlling the laser system which works with special CAD-CAM software. They have been engraved 5 *5 mm2 Square cavities on plane samples with varying in the used parameter where they used, 10, 40, 70, 100 and 200 mm/s scanning speed, from 2500-3500 Hz the range of pulse frequency and the number of scanning geometries range of 1-10 which indicated as repetitions (R) while the distance between each linear pattern which called step (st) fixed at 70 mm. They also refer to the homogeneity of used material as an important parameter especially in wood engraving which effect on the material removal rate leads to a discontinuity in the surface deeply, so that the engraving on Mahogany, Walnut, and Poplar wood was preferable on another kind like chestnut oak and pine. From their result, they found that at speed up to 10 mm/s the surface carbonization was observed and at more than 40 mm/s low engraving depth is observed then a multiple laser scanning is required for deep engraving. The defect in this study was in the experiment they use try and error instead of using the design of the experiment.

Takayama et al. worked on developing micro-structures with deep V-shaped grooves using a nanosecond pulsed Nd: YAG

e-ISSN: 2321-6212
p-ISSN: 2347-2278

laser with 532 nm and 1 W maximum power to make deep grooves in sapphire [20]. They used the taper angle as an affected parameter on engraving the groove which controlled by the laser flounce, scanning speed and incident angle of the laser beam. The sapphire used is a single-crystal cube with a length of 10 mm. COMSOL multi-physics software was used for irradiated temperature Simulations. In their result, they discussed the effect of consecutive irradiations, focal plane position, laser fluence, scanning speed, incident angle, and Machining of pyramidal structures. They found that the Laser fluence and the ablation threshold of the material determine the taper angle. In addition to the taper angle increases, the incident flounce decreases. The taper angle becomes constant when the incident fluence reaches the ablation threshold, no more machining can take place. They observed greater smoothing e□ect at high-speed on the groove bottom lead to surface machine-ability decreasing. The operation of sharp micro-structures with steep walls becomes possible by using the taper formation technique for laser micro-machining. Despite their good results which have been obtained from the simulation program, but the results should be compared with experimental work.

Fiber Laser

This laser was a great tool for industrial application because of its ability to cut, engrave, etc. many types of material which were greatly used in industry. From its name, fiber laser was that laser where it has active medium contained from optical fiber doped with a rare earth element, including erbium (Er), neodymium (Nd), and ytterbium (Yb) and pumped with a diode laser. The output power of this laser up to hundreds of watts with high efficiency. This laser has many advantages are compacts design, a beam of high quality, the generation of ultra-short pulse laser beams and high tun-able range as well as high output efficiency about 50% as compared with CO_2 and Nd: YAG which was 10-30%, 2% respectively. Also, these laser has some disadvantages are the difficulty to align the pump beam to the core of a single mode optical fiber. The output power was limited to hundreds of watts because of the damaging of fiber at high pumping. Also, it needs to long cavity length because limiting in absorption per unit length of fiber [3]. This laser is widely used in the industrial application like cutting, welding, engraving, drilling and surface treatment. The importance of this laser lies in the material affected in it like Laser Cutting Mild Steel, Stainless Steel, Nonferrous Metal, Precious Metals and Titanium which not affected by CO_2 laser also it was used for glass, plastic, wood and other organic material. So that it was used for marking or engraving different material and its effect has been studied for different researchers as will show.

Kasman and Saklakoğlu has investigated the deep engraving, laser operation on tungsten carbide utilizing 30 W solid state ytterbium-doped fiber laser having a wavelength of 1064 nm [21].

The mathematical model was constituted for surface roughness and engraving, deep. In their work, a practical study on the machinability of tungsten carbide utilizing laser deep engraving technique was presented. Also, they determined the effect of laser parameter including the power of the laser beam, scanning speed, the frequency and fill space on the surface roughness and engraving depth. The focal length of the scanner used has been adjusted at a 175 mm. They made a controlling on the engraving process utilizing a marking program. They found that surface roughness and engraving depth has been reduced by raising both the scanning speed and fill spacing. In addition to incrementing in frequency raises the surface roughness while reducing the depth of engraving. Both surface roughness and the engraving depth increased by increasing the output power of the laser. The lowest surface roughness was obtained when the control factors at 800 mm/s, 40 kHz, 75% and 0,04 mm and the measured surface roughness was 1,22 μm. The highest engraving depth was obtained when the control factors at 200 mm/s, 20 kHz, 100% and 0,02 mm and measured surface roughness is 102,35 μm. These processes are the more powerful technique for machining the high hardness material compared with traditional method. However, the use one value for the power which gives same weaken for their work because the power was one of the most important parameters in the engraving process.

Kasman and Saklakoğlu they have been studied the effect of the scan times on surface roughness and engraving depth [21]. An experimental design was implemented to AISI H13 tool steel workpiece using 30 W solid state ytterbium-doped fiber laser having a wavelength of 1064 nm. In their work, an experimental design plan was constituted using full factorial design and results were evaluated for surface roughness and engraving depth. The main contribution of their work was that they produced new evidence regarding which were the effects of the multi-scan times on both surface roughness and engraving depth for laser engraving AISI H13. Their results showed that the scan speed and the scan times have great influence on surface roughness and highest engraving depth. Conversely, the frequency has little influence. In order to minimize the surface roughness, the scan speed should be decreased, on the other hand, it causes a decrease in engraving depth. It was important to ensure that both SR and D aren't improved at the same conditions where an increase in scan time increases engraving depth and surface roughness. The regression model for surface roughness and engraving depth have been significant at the 0.05 level, P=0,000. This work contribution was studying the effect of multi-scan time on surface roughness and engraving depth. Despite considering this new factor for the engraving process, but it has a disadvantage which was increasing the surface roughness which considered a defect on the material surface, as well as the multi-scan on the same place, may be led to weakening in the same material and led to being broken, reduce the resistance or corrosion [22].

Saklakoglu and Kasman studied the effect of process parameters on the surface form of laser engraved H13 tool steel [23]. Their study focused on recast layer formation and subsurface hardness as a function of distance. The experimental studies have been performed by using a marking machine combined with a ytterbium-doped fiber laser with a wavelength of 1064 nm and

e-ISSN: 2321-6212
p-ISSN: 2347-2278

an output power of 30 W. The motion of the laser beam and the process parameters were controlled by a PC. Eight experiments based on laser engraving parameters (laser power, scan speed, frequency) with an optimal value for minimum surface roughness and depth were performed for the investigation. The parameters which significantly affect the recast layer thickness are the power and scan speed. The high hardness was detected at 201 HV, which measured at 800 mm s^{-1} for scan speed and 40 kHz for frequency. XRD analysis showed that two different phases, Fe and Fe2.96 Si 0.05 O4, existed on the machined surfaces.

Patel and Patel used the fiber laser on Stainless Steel (304) to study the effect of engraving process on surface roughness measurement [24]. In their work, they use different Frequency (20, 50, 80 kHz), different engraving speed (100, 300, 500 mm/Sec) and a different number of passes (10, 15, 20), on the stainless steel (304) sample with 1.5 mm thickness. The Akshar Fiber-Pro laser engraving machine has been used with 1060 nm wavelength with the nominal output power of 20 watt. They conduct their experiments using full factorial design to get the best engraving quality. From their results, they showed that the surface roughness was higher at 20 KHz frequency, 100 mm/Sec engraving speed with 10 passes number. Also, it becomes lower at a maximum frequency of 80 KHz. From their result, they improve in the hardness of the recast layer to two times higher than 200 µm. However, their result showed many defects, like the cracks and solid droplets in addition to voids appear in the surface which was not accepted in many application and consider as a disadvantage for this work.

Patel and Patel investigated the parametric optimization of the laser engraving process on SS 304 using Gray Relational Technique [25]. Fiber laser engraving machine was used in the engraving process with mean power 20 w, wavelength 1060±10 nm and pulse duration <120 ns. They use the engraving laser machine with various parameters that considered affected on the substrate where the variable input parameters are frequented (20, 25, 30 kHz), engraving speed (100, 200, 300 mm/Sec), and number of passes (30, 50, 70) and the output parameters are surface roughness, indentation, and material removal rate. The optimization was done for all parameters with multiple responses by gray relational analysis. They found that the optimum parameter level of frequency, engraving speed and the number of passes is level 1 (20 kHz), level 2 (200 mm/Sec) and level 3 (70 passes) respectively. From their test, they have been obtained about 3.01368 mm of surface roughness, addition to 170 microns for material removal rate of 0.14524 with 8.65 % error in surface roughness and 4.32 % error in material removal rate. From their results, they showed the best roughness, indentation, predictability of material removal rates, and the ability to apply such industrial laser engraving to have the best quality of engraving by effective selection of a manufacturing. However, they use a constant value for laser power which considers the most important parameter for this process.

Vladan Mladenovič et al. investigated the effect of fiber laser engraving on cold rolled AISI 304 stainless steel using a response surface methodology [26]. The computer program Visual Laser Marker has been used to design the engraving experiments. The 300FL (Gravograph) fiber-laser engraving machine was used with a maximum average laser power of 30 W and a wavelength of 1064 nm. The experimental designs were done using the L27 Taguchi standard orthogonal array where 27 experiments performed for this design of the experiment. Their study showed that the scan speed was the main parameters that affect on the removal rate, the groove depth and the groove width. Also, the lower scan speed and a higher power were resulting in a higher cross-section area, a deeper groove and a wider groove. The groove's width increases at lower power, while it decreases at higher power (p above 12,5 w) while using the higher laser power and high pulse frequency (50-150 kHz) have no effect, but there is a limited impact on groove width. A smaller groove width could be obtained at a high pulse frequency, by the shifting the focus above the substrate surface. A good work was done in this paper, their experiment was done using L27 deign of experiment. Also, they get a good result which can be used in micro-fluidic application. The result showed little pores and oxide layer, but so much little so it was not considered as defect in the work.

CONCLUSION

The conclusion was done for all researcher from the older one to this year showing the type of laser used, the used material, results and the application or benefit from each work (**Table 1**).

Table 1: Results and the application or benefit from each work.

Authors	Laser type	Material	Result	Application
Jerry Ehrenwald and et al.	Nd: YAG laser	Diamonds	Obtained that the engraved character size in the range from 25-125 microns in height and width and less than 25 microns for the line width addition to less than 50 microns from the depth	Engraving on jewelry
Donald G et al.	CO_2 laser	Photopoler	High quality engraved photopolymer plates without using a graphic art film or photographic masks	Printing on photopolymer
Qi et al. [17]	Nd: YAG laser	Stainless steel	The mark depth reaches its maximum value at 3 KHz while the width kept constant with varying the pulse frequency value. Also, the evaporation of material decrease with increasing the pulse frequency as well the oxidization becomes significant that lead to improvements in the marked contrast. The maximum mark contrast has been found at 8 KHz of laser pulse frequency.	Improve the marking on stainless steel
Allan Bereczki et al.[18]	Nd: YAG laser	A hard steel	This strategy brought about a variable, quick and economical process	Produce a three-dimensional surface

e-ISSN: 2321-6212
p-ISSN: 2347-2278

Mohd Ashraf B and Mohd Fauzan	CO_2 laser	304-grade stainless steel	The engraving width was greatly affected by cutting speed and the interaction between power and speed	Micromachining on stainless steel
Leone et al. [19]	Nd: YAG laser	Wood	At speed up, to 10 mm/s the surface carbonization was observed and at more than 40 mm/s low engraving depth is observed, then a multiple laser scanning is required for deep engraving. Also, the depth of engraving was strongly affected by the power, the pulse frequency, the beam speed and the repetition number.	Engraving on wood
Şefika Kasman and İ. Etem Saklakoğlu [21]	Fiber laser	Tungsten carbide	The lowest surface roughness was obtained when the control factors at 800 mm/s, 40 kHz, 75% and 0,04 mm and the measured surface roughness was 1,22 µm. The highest engraving depth was obtained when the control factors at 200 mm/s, 20 kHz, 100% and 0,02 mm and measured surface roughness is 102,35 µm.	Deep engraving
Sefika Kasman and. Etem Saklakoglu [21]	Fiber laser	AISI H13	SR and D aren't improved at the same conditions where an increase in scan time increases engraving depth and surface roughness. The regression model for surface roughness and engraving depth have been significant at the 0.05 level, P=0,000.	Engraving on AISI H13
Wangui et al. [13]	CO_2 laser	Perspex and soda lime glass	By increasing the incident angle the kerf width increase and the engraving depth decrease, also both the kerf width and engraving depth become larger in engraving at the lower speed	The cooling holes in certain parts of the aero-engine component and in vias marking
Aichinger and et al.	CO_2 laser	-	The output quality was improved by using complex error correction of the hardware	In industrial for graphic and design branches
Saklakoglu and Kasman [23]	Fiber laser	H13 tool steel	The high hardness was detected at 201 HV, which measured at 800 mm s−1 for scan speed and 40 kHz for frequency. XRD analysis showed that two different phases, Fe and Fe2.96 Si 0.05 two different phases, Fe and Fe2.96 Si 0.05 04, existed on the machined surfaces.	recast layer formation and subsurface hardness as a function of distance
Genna and et al.[15]	CO_2 laser	poly-methyl-. Methacrylate (PMMA) sheet	The removal rate and the roughness were changed by changing the scanning speed where it decreases with increasing the scanning speed and increases it by changing the wave mode from CW to PW at 15 kHz to pulsed-wave at 2 kHz	Engraving on PMMA plate
Patel and Patel [24]	Fiber laser	Stainless Steel (304)	The surface roughness was higher at 20 KHz frequency, 100 mm/Sec engraving speed with 10 passes number. Also, it becomes lower at a maximum frequency of 80 KHz.	Get the best engraving quality
Patel and Patel [24]	Fiber laser	SS 304	Optimum parameter level of frequency, engraving speed and a number of passes are level 1 (20 kHz), level 2 (200 mm/Sec) and level 3 (70 passes) respectively. Also about 3.01368 mm of surface roughness, addition to 170 microns for the material removal rate of 0.14524 with 8.65 % error in surface roughness and 4.32 % error in material removal rate.	Ability to apply such industrial laser engraving to have the best quality of engraving by effective selection of a manufacturing.
Shou Xiang Jiang et al.	CO_2 laser	The foil-laminated denim	With the increase in the resolution, a clear pattern could be produced and higher pixel time can export more energy which makes the pattern look more clearly	Opens up new possibilities for metallic denim fabric design without any chemicals used
Vladan Mladenovič et al.	Fiber laser	Cold rolled AISI 304 stainless steel	Lower scan speed and a higher power were resulting in a higher cross-section area, a deeper groove and a wider groove. The groove's width increases at lower power, while it decreases at higher power (p above 12,5 w)	Intaglio printing (e.g., banknotes and passports)
Nozomi Takayama et al.	Nd: YAG laser	Sapphire	Laser fluence and the ablation threshold of the material determine the taper angle, as well as the taper angle increases, the incident fluence decreases, and the taper angle, become constant when the incident fluence reaches the ablation threshold	A 3-dimensional micro-pyramid structure could be machined, by using a 2-dimensional laser scanning system

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e-ISSN: 2321-6212
p-ISSN: 2347-2278
DOI: 10.4172/2321-6212.1000234

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