Reason- A Technical Journal
ISSN 2277-1654
Volume XIII • 2014

Nd: YAG LASER MARKING ON ALUMINIUM

Josephine Peter[1], B. Doloi[2] and B. Bhattacharyya[3]

Production Engineering Department, Jadavpur University, Kolkata-700032, India
Email: [1]joshiriyapeter@gmail.com, [2]bdoloionline@rediffmail.com
[3]bb13@rediffmail.com

Paper received on: January 29, 2014, accepted after revision on: February 20, 2015

Abstract: Nd: YAG Laser marking is flexible, programmable and environmentally clean process, which can indelibly mark at very fast speeds. The present paper deals with the analysis of laser marking process parameters like lamp current, laser scanning speed, pulse frequency of laser beam using Nd: YAG laser on various laser marking characteristics like the mark width, mark depth and mark intensity are studied during pulsed Nd: YAG laser marking on aluminium. The present study shows that high pulse frequency and lamp current with low scanning speed has more effect to achieve the minimum mark width, maximum mark depth. Also high pulse frequency and scanning speed has more effect on the mark intensity. In addition to it, analysis based on optical photographs has also been performed.

Keywords: Pulsed laser, Nd: YAG laser, laser marking, mark width, mark depth.

1. INTRODUCTION

Nd: YAG lasers have unique ability to deliver a stable, high intensity source of light of small spot diameter, which is the best choice for laser marking. Laser marking is essentially a thermal process that employs a high intensity beam of focused laser light to create a contrasting mark on the material surface. Nd: YAG lasers produce high peak power, which is major requirement to mark different engineering materials. Nd: YAG laser marking has great potential in diverse range of applications i.e., electronics components, automotive products, medical implants and surgical instruments, etc. Laser marking is non-contact process [1], best and most applied technique to make permanent marks on a wide range of materials, which is indeed used to identify [2] and trace products in a production line, but also during its entire lifetime. Alphanumeric, graphics, logos, barcodes and even bitmaps can be marked. Laser marking can be used for showing production information like barcodes manufacturer's name, model number [3, 4], imprinting complex logos. Laser marking provides an elegant solution when a clean, fast, non-contact marking process is required to produce an indelible high-quality mark. Laser marking offers many advantages compared with conventional marking methods, such as no wear on tools, sharp, high quality markings, low operating cost, non-contact and high degree of automation [5, 6]. Moreover the key features like high peak power, unique ability to deliver a stable, high intensity source of light of small spot diameter makes it a best choice for laser marking on different engineering materials. Lehmuskero et al. [7] used pulsed YLP fiber laser to mark on AISI 304L stainless steel grade and obtained different colours by varying the process parameter of laser scanning speed and the line spacing between the marks. Leone et al. [8] carried out laser marking tests on AISI 304 steel, using a Q-switched diode pumped Nd: YAG laser to determine the correlation occurring between working parameters and mark visibility. Peligrad et al. [9] described two dynamic models relating processing parameters and melt pool width during laser marking of clay tiles using a high-power diode laser. Dascalu et al. [10] used Nd: YAG laser at fundamental and second harmonic generation and it was moved on the piece of material to be faded by a set of two computer-controlled scanning mirrors, thus producing a fading in the irradiated area of the laser beam.

Aluminium is increasingly used in micro systems technology such as electrodes in biotechnology applications [11]. The established approach to the manufacture of many of the micro parts that incorporate aluminium is either electrochemical machining, photo-lithography using mask projection techniques, and/or micro electro-discharge machining (EDM). Each of these processes has its inherent advantages and disadvantages. The use of a direct-write approach to laser micromachining is seen as an economical alternative. The focused laser spot therefore becomes the machining tool. The precision obtainable with this method is determined by a combination of the optical properties of the laser light emitted from the cavity and the optical arrangement used to propagate and focus the beam onto the workpiece surface. It has been found that very few works have been done on aluminium, hence it a growing need to analyze marking done on aluminium. This paper analyses the influence of the major laser process parameters like pulse repetition rate, lamp current, and scanning speed on the marking characteristics i.e., mark width, mark depth and mark intensity.

2. EXPERIMENTAL SET UP FOR Nd: YAG LASER MARKING

Experiments were conducted by using CNC controlled laser machine which employs pulsed Nd: YAG laser with a wavelength of 1064 nm with a TEM00 mode of operation. The laser beam was focused with a lens of 50 mm having a spot size of 0.1mm. The work piece was held in a fixture over the X-Y table. The work piece was monitored with the help of CCD camera. A CCTV was used to view the work piece in order to set the focal length so as to focus the beam accurately for proper machining. Experiments were performed with the aid of compressed air. Fig.1 shows the schematic representation of CNC controlled pulsed Nd: YAG laser system.

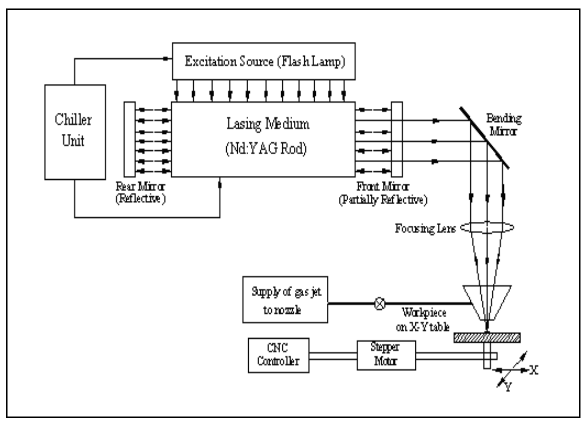


Fig. 1 Schematic representation of CNC controlled pulsed Nd: YAG laser system

The material used for the experimental purpose was aluminium. Regular geometric shapes were created with a help of Coreldraw 5.0 software. It was then interfaced by Multisaw software for the movement of CNC X-Y table. Regular geometric shapes were marked under different marking parameters. The profiles were tested and measured using Olympus micrometer.

3. ANALYSIS BASED ON EXPERIMENTAL RESULTS

Based on the trial experiments, the range and combinations of input process parameters are selected, the effects of different process parameters like the pulse frequency, lamp current and scanning speed on responses like the mark width, mark depth, and mark intensity during laser marking have been analyzed.

3.1 Effect of Pulse Frequency

Pulse frequency is one of important parameter, which influences the marking characteristics. Fig.2 shows the effect of pulse repetition rate on the mark width for different lamp current and by keeping all other laser processing parameters constant as scanning speed as 15 mm/s, pulse width as 3 % and air pressure of 1.5 kgf/cm^2. When the pulse frequency increases the mark width decreases, but shows an increasing trend with the raise in lamp current. When the pulse frequency is increased, the peak power delivered is not sufficient enough to remove more material and thus results in a narrow width. The relation between peak power and the average power is given by the following equation.

Peak Power (P_{peak})= Average Power (P_{avg})/ [Pulse Frequency (f) x Pulse Duration (μ)]

Mark width depends on the focused spot size. Increase in the pulse frequency, the spot size decreases which lead to finer marking, which is clearly seen from the figure.

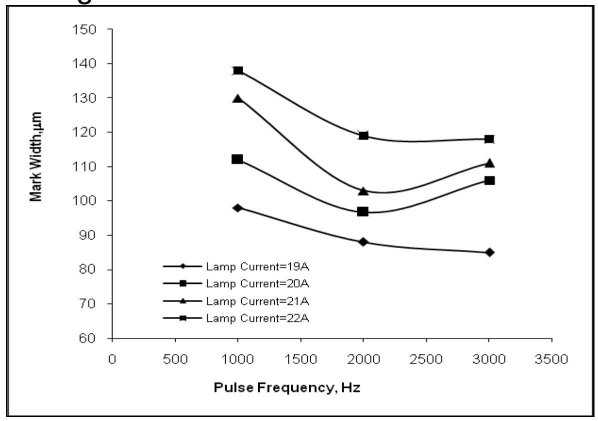


Fig. 2 Variation of mark width with pulse frequency

The effect of pulse frequency on the mark depth is studied from the Fig.3 by keeping all other parameters as constant as above. With the variation of the pulse frequency, the mark depth shows a slight increase and when the pulse frequency is increased further, it shows a small decrease. It is also found that the mark depth increases gradually for lower values and rapidly for the higher values of pulse frequency. This is due the fact that as the lamp current increases the laser power supplied to the work piece also increases which ultimately increases the depth of the mark.

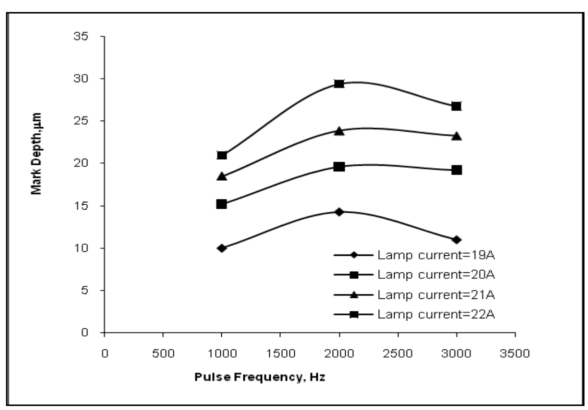


Fig. 3 Variation of mark depth with pulse frequency

The change in the mark intensity with the variation of pulse frequency is seen from Fig. 4. With the increase in the pulse frequency, there is an increase in the mark intensity. As the pulse frequency increases the power reaching the work piece is less and hence there is redeposition of the evaporated material on the surface which leads to the increase in the mark intensity. Also with the increase in the lamp current, it is observed that there is an increase in the mark intensity.

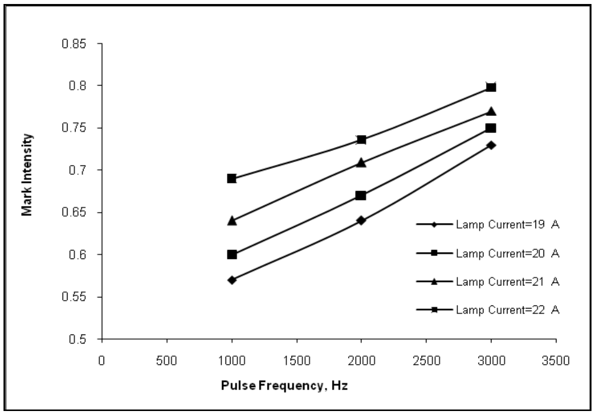


Fig. 4 Variation of mark intensity with pulse frequency

3.2 Effect of Lamp Current

The lamp current is one of the measures of the power or energy of the laser beam to heat and remove the material. So with the increase in lamp current there is an increase the laser power output. Fig.5 shows the variation of mark width for different lamp current with the variation of the pulse frequency by keeping other laser marking parameters constant as scanning speed as 15 mm/s, pulse width as 3 % and air pressure of 1.5 kgf/cm^2. From the figure it can be seen that as the lamp current increases the mark width increases. When the lamp current is raised, the energy delivered by the laser beam also increases, which is the major factor for the increase in the mark width.

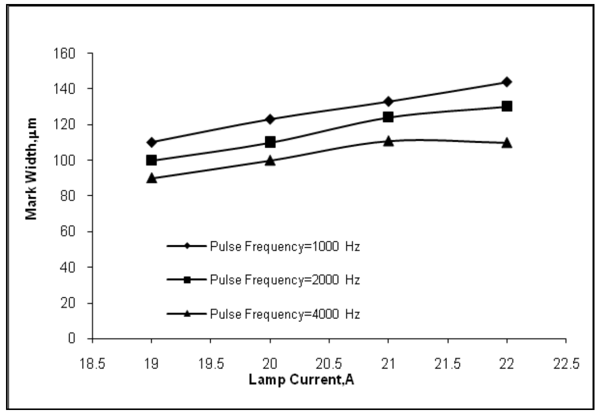


Fig.5 Variation of mark width with lamp current

The influence of lamp current on the mark depth can be analyzed from Fig. 6 with the variation of the pulse frequency at constant scanning speed of 15 mm/s. With the increase of lamp current the mark depth increases. As the lamp current is raised, the laser beam intensity also increases which causes more material removal thereby resulting in more mark depth. Further the energy of the laser beam also increases which results in more melting and vaporization of the material from the focused surface.

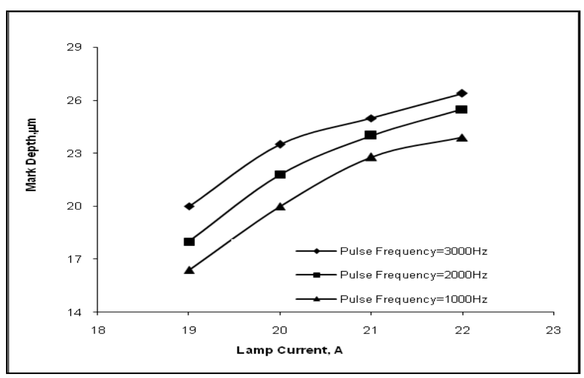


Fig. 6 Variation of mark depth with lamp current

The effect of lamp current on the mark intensity is studied from Fig.7 with the variation of pulse frequency. From the figure, it is seen that the mark intensity increases with the increase in the lamp current for low frequency, but shows a slight decrease with the increase in the pulse frequency. Even though the lamp current is more, with the increase in the pulse frequency mark intensity decreases.

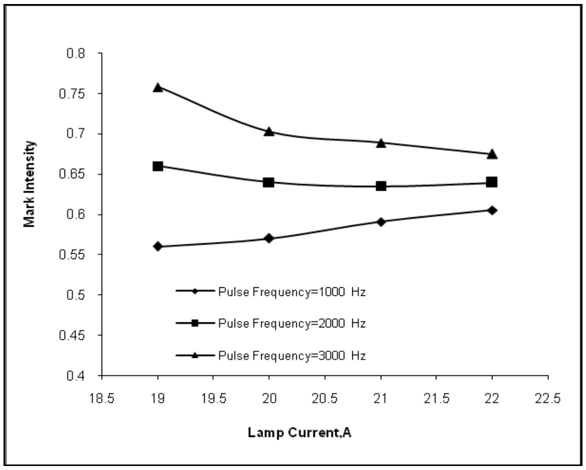


Fig. 7 Variation of mark intensity with lamp current

3.3 Effect of Scanning Speed

In laser marking, the scanning speed is other important process parameters. For deep marking, each point on the marked line will require exposure to several pulses to achieve depth. The influence of scanning speed on the mark width can be analyzed from Fig. 8 by keeping other parameters like the lamp current as 20 A, pulse width as 3% and air pressure as 1.3 kgf/cm^2. The mark width decreases more steeply for low values of pulse frequency with the increase of the scanning speed. As the scan speed increases the duration of laser delivered per unit spot area is reduced which leads to less energy transfer and finally marked line width reduces due to less amount of material removal. It is also found that there is a gradual decrease with the increase in pulse frequency.

Fig. 9 illustrates the effect of scanning speed on the mark depth by varying the pulse frequency at constant lamp current of 21A. From the graph it is clearly understood that the mark depth decreases drastically for lower values of pulse frequency but increases gradually for the higher values. At low scanning speed the time available for the material removal is more, which aids in more depth. As laser interaction time plays a major role, it affects the mark depth, which finally has an effect in the mark quality.

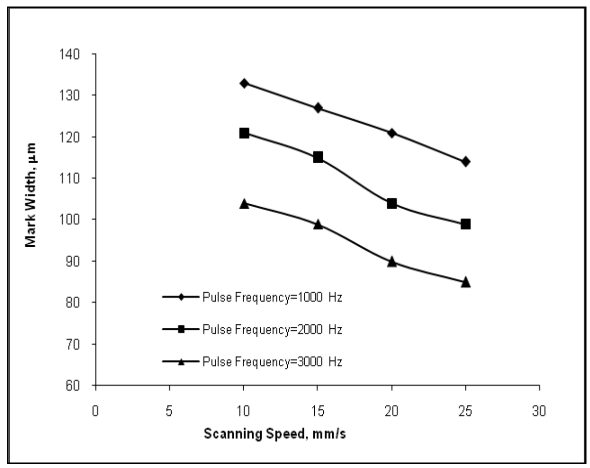


Fig. 8 Variation of mark width with scanning speed

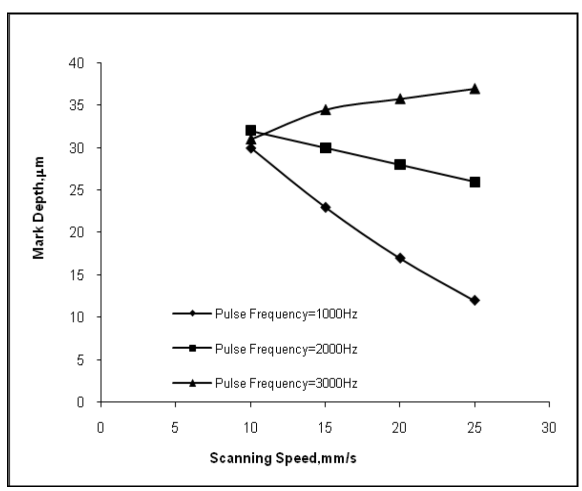


Fig. 9 Variation of mark depth with scanning speed

The effect of scanning speed on the mark intensity is studied from the Fig. 10 with the change in the pulse frequency. It is observed that there is an increase in the mark intensity when the scanning speed is increased for low values of pulse frequency and decreases when the pulse frequency is high. As the scanning speed is increased the time available for the laser at a spot is less which causes incomplete evaporation of the material thereby leading to more mark intensity.

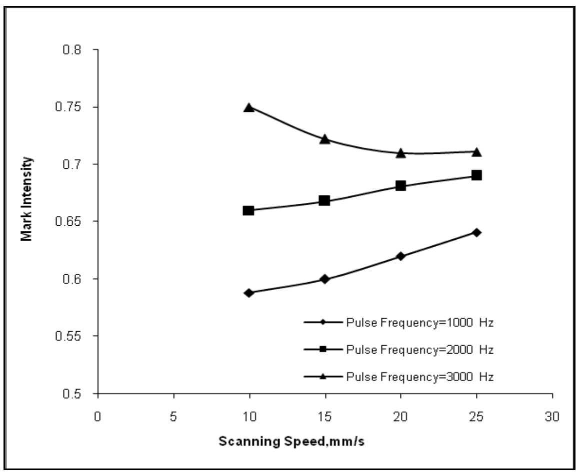
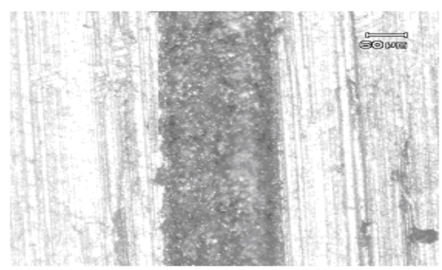


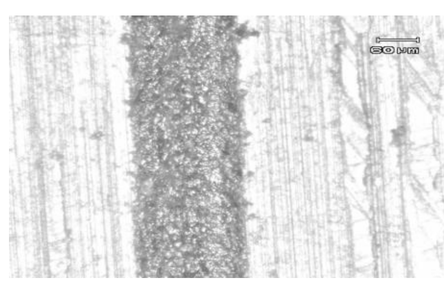
Fig. 10 Variation of mark intensity with scanning speed

4. ANALYSIS BASED ON PHOTOGRAPHS

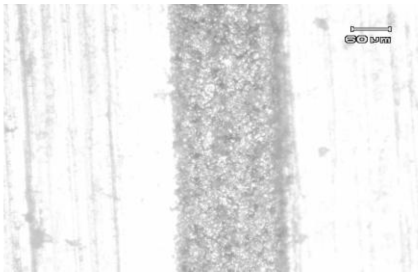
Laser marking characteristics at different parametric setting are analyzed form the various figures, which are exhibited in Fig.11(a)-(f). The optical photographs were taken with OLYMPUS STM 6 microscope with the magnification of 10X. The figures (a) - (b) are marked at increasing pulse frequency from 1000 Hz to 3000 Hz by keeping all process parameters constant as lamp current 21A, pulse width 3% and air pressure of 1.5 kgf/cm^2. It is seen that the mark width decreases with the increase in the pulse frequency and the mark intensity increases with the increase in the pulse frequency. From the Fig.11(c)-(d), it is observed that there is a reduction in the mark width when the scanning speed is increased from 10 mm/s to 20 mm/s by maintaining all other process parameters constant. Also there is an increase in the mark intensity with the increase in the scanning speed. It is observed that the marking is continuous for low scanning speed but it is discontinuous for high scanning speed due to the non-availability of laser at that spot to vaporize the material. Fig.11(e)-(f) shows the transverse section of the laser mark from which the mark depth can be seen. It is observed that there is an increase in the depth when the lamp current is increased from 20 A to 23.



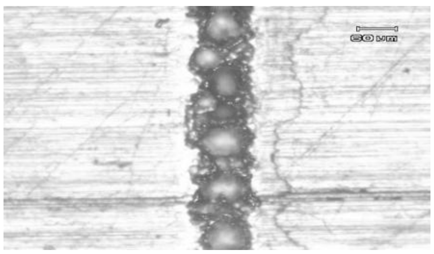
(a) Pulse frequency- 1000 Hz



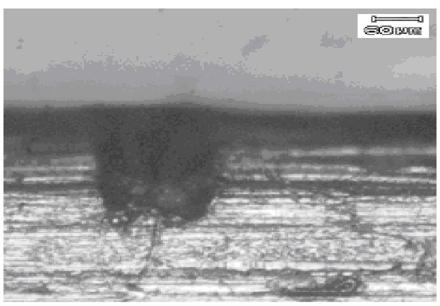
(b) Pulse frequency- 3000 Hz



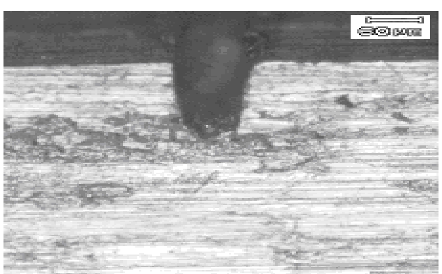
(c) Scanning speed- 10 mm/s



(d) Scanning speed- 20 mm/s



(e) Lamp current- 20 A



(f) Lamp current- 23 A

Fig.11(a-f) Optical photographs of marking at different setting of lamp current and scanning speed pulse frequency, by keeping pulse width as 3% and air pressure as 1.3 kgf/cm^2

5. CONCLUSIONS

Laser marking is an effective alternate permanent marking process, which offers greater flexibility. The present experimental investigation shows the influence and dependence of laser marking process parameters like lamp current, pulse frequency and laser scanning speed for effective laser marking criteria i.e. laser mark width and mark depth on the Nd: YAG laser marking on aluminium. It can be concluded from the present analysis that high pulse frequency and low lamp current has more effect to achieve minimum laser mark width compared to other process parameters. It can be also concluded that scanning speed also plays a major role in the mark depth as low scanning speed aids to achieve greater mark depth. Moreover, high pulse frequency and high scanning speed has a predominant effect on the mark intensity. In addition to it, the optical photographs, which are exhibited, also prove the analyses on the aluminium.

Acknowledgment: The authors acknowledge the financial support provided by CAS Ph-IV program of Production Engineering Department of Jadavpur University under University Grants Commission (UGC), New Delhi.

REFERENCES

[1] Chen, T.C. and Darling, R.B., Parametric Studies on Pulsed near Ultraviolet Frequency Tripled Nd:YAG Laser Micromachining of Sapphire and Silicon, Journal of Materials Processing Technology, Vol.169, pp.214–218, 2005.

[2] Restrepo. J.W, Fernandez, J.M.P., Gomez, M.A., Serra, P. and Morenza, J.L., Influence of Preheating and Hematite Content of Clay Brick Pavers on the Characteristics of Lines Marked with a Nd:YAG Laser, Applied Surface Science, Vol.253, pp.2272–2277, 2006.

[3] Jangsombatsiri, W. and Porter, J.D., Laser Direct-Part Marking of Data Matrix Symbols on Carbon Steel Substrates, Journal of Manufacturing Science and Engineering, Vol.129, pp.583-591, 2007.

[4] Park, Y.W. and Rhee, S., Study of a Line Width Estimation Model for Laser Micro Material Processing Using a Photodiode, Optics & Laser Technology, Vol.39, pp.1461–1471, 2007.

[5] Dascalu, T., Ortiz, S.E.A., Morales, M.O. and Compean, I., Removal of the Indigo Color by Laser Beam-Denim Interaction, Optics and Lasers in Engineering, Vol.34, pp.179-189, 2000.

[6] Qi, J., Wang, K.L. and Zhu, Y.M., A Study on the Laser Marking Process of Stainless Steel, Journal of Materials Processing Technology, Vol.139, pp.273–276, 2003.

[7] Lehmuskero, A., Kontturi, V., Hiltunen, J. and Kuittinen, M., Modeling of Laser-Colored Stainless Steel Surfaces by Color Pixels, Applied Physics B, Laser and Optics, Vol.98, pp.497-500.

[8] Leone, C., Genna, S., Caprino, G. and Iorio, I.D., AISI 304 Stainless Steel Marking by a Q-Switched Diode Pumped Nd:YAG Laser, Journal of Materials Processing Technology, Vol.210, pp.1297–1303, 2010.

[9] Peligrad, A.A., Zhou, E., Morton, D. and Li, L., Dynamic Models Relating Processing Parameters and Melt Track Width during Laser Marking of Clay Tiles, Optics & Laser Technology, Vol.34, pp.115–123 2002.

[10] Dascalu, T., Sofia, E.A.O., Martin, O.M. and Isaac, C., Removal of the Indigo Color by Laser Beam-Denim Interaction, Optics and Lasers in Engineering, Vol.34, pp.179-189, 2000.

[11] Haefliger, D., Cahill, B.D. and Stemmer, A., Rapid Prototyping of Microelectrodes on Glass and Polymers by Laser Assisted Corrosion of Aluminium Films in Water, Microelectron Eng, Vol.1, 2003.