Physics AUC, vol. 33, 98-102 (2023) **PHYSICS AUC**

Effect of Laser Ablation Rates on Industrial and Recycled Aluminum Alloy

L. BAZIZ[1] and A. NOUIRI[2]

[1]Department of Science and Technology, University center Abd-Elhafid Boussouf Mila, Algeria

[2]Departement of Physics, University Larbi Ben M'hidi Oum El Bouaghi, Algeria

Emails: l.baziz@centre-univ-mila.dz nouiri.kader@gmail.com

Abstract

The manufacture of metallic nanoparticles by laser ablation remains a concern of the global industry. For that we are interested in this work to study the variation of laser ablation rates for two types of commercial aluminum alloys (industrial and recycled aluminum). The surface is irradiated by Nd: Yag laser (λ = 532 nm, with a pulse duration of 15 ns and an energy of 50 mJ) and the ablation depth is measured by a profilometer.
The experimental results show that a linear relationship between the ablation depth and number of shots. The ablation rate is more important in industrial aluminum than the recuperated and depends to the composition of material and the fluence of the laser or the ablation threshold fluence of each irradiated alloy. So we can control the machining speed by change ablation rates.
Keywords: ablation laser, aluminum alloys, the ablation rate.

1. Introduction

Laser ablation is a direct, low-destructive technique that plays an important role in the machining and structuring of materials. Their applications can range from high-precision drilling and marking to the manufacture of complex surface patterns [1]. Laser ablation micromachining offers many advantages, such as simple engraving; precision, which depends on the type of laser used; relatively high speed; the ability to machine different materials; and low cost, both in terms of equipment and machining costs. This technique is based on laser-matter interaction over short timescales ranging from a few ns [2] to several hundred fs [3]. It is also possible to ablate with nanosecond lasers. Very good results have been obtained with the latter, at a much lower cost [4].
Many other works have been reported in the literature on the production of micro and nanostructures using laser ablation [5-7]. To properly control the applications of this technique, the ablation rate plays a very important role. This technique determines the proportion of ejected material reduced to a single pulse and is expressed in spatial units per pulse. It depends on the parameters of the process (fluence, focal length, number of pulses ...) and the properties of the material (electronic and crystallographic structure, optical and thermal absorptions) [8,9].
Two categories of rates stand out:

– The depth ablation rate, which we will simply call the ablation rate (diameter is not taken into account) (μm / pulse);

– The volume ablation rate, which we will call the volume rate (diameter of the crater is also taken into account) (μm^3 / pulse). In the same context, Yoan Di Maio [9] studied different methods for determining the ablation rate in different materials. Motivated by this work, we aim to study two methods (depth ablation rate and volume ablation rate) on industrial and recycled aluminum used in manufacturing. Furthermore, laser ablation is characterized by the engraving speed or depth ablated per pulse. In some cases, ablation curves (depth ablated per pulse as a function of energy density "fluence") have a general appearance very close to that of a linear function of the logarithm of fluence. This variation is modeled by a Beer-Lambert relationship. A photoablation model has been proposed by Srinivasan [10]. Which describes ablation as a volume explosion of the irradiated material. This model can be broken down into three distinct and successive stages: absorption of the incident light; rupture of the bonds, leading to an overpressure in the zone affected by the radiation; ejection of the fragments. In this model, the ablation mechanism is essentially photochemical. The estimated ablation velocity follows the derivative function of the Beer-Lambert law [11, 12].

2. Experimental

The samples studied are two materials, industrial and recycled aluminum alloys. They were polished mechanically and cleaned. The chemical composition of each type is obtained by X-ray analysis[13]. The chemical composition of recycled aluminum alloy is Al(72.02 wt %), Si(13.05 wt %), Zn(6.34 wt %), O(4.28 wt %), Mg(2.08 wt%), Cu(1.75 wt %), and Ni(0.48 wt %). The chemical composition of industrial aluminum alloy is Al(83.10 wt %),Cu(5.47 wt %), Fe(4.12 wt %), O(2.71 wt %), Mn(1.74 wt%), Si(1.66 wt %), and Mg(1.20 wt %)[14]. A nanosecond pulsed laser (Nd:Yag) is used to irradiate an aluminum alloy sample. The instrument used in this experiment is the Spectrum laser system. The laser used is a Q-Switch Nd: YAG Brilliant (Quantel). The Bar is pumped by flash lamps, and delivers 300 mJ per pulse atλ=1064µm.Thedubbing is often made with a crystal KDP output of the laser, and allows for 160 mJ per pulse at λ = 532 nm. A diachronic mirror, positioned behind the crystal doubler, cannot recover the beam atλ=532nm.The measures of the irradiated area are studied by the profilometer instrument in order to measure the ablation depth.The properties of material studied are reported in the Table1.

Table1. Main properties of the two alloys studied (compared with pure Aluminum)

Aluminium	recycled	industrial	pure
Density	**2816**	**2614**	**2700**
Microhardnes	**118**	**125**	**2.75**
(kgF/mm^2)	**128**	**160**	**237**
Thermal Conductivity			
(W/m.K)	**7**	**10**	**0.23**
Ablation threshold			
(j/cm^2)			

3. Results and discussion

Ablation depth as a function of the number of shots (pulses) is presented in Fig.1. A linear relationship between these two parameters is observed. On the other hand, and because of this linear relationship, the ablation rates are then determined for different beam energies from slope [15]. Figure 1 shows the variation in ablation depth in terms of the number of shots. Sample ablation is evident even at the lowest fluence. It is interesting to note that ablation depth increases rapidly for higher shot numbers, and after 80 shots, saturation is observed in the recovered aluminum. Saturation is associated with a drop in machining efficiency. Like incubation, it is caused by the accumulation of a large number of pulses, this time affecting the geometry of the interaction interface.

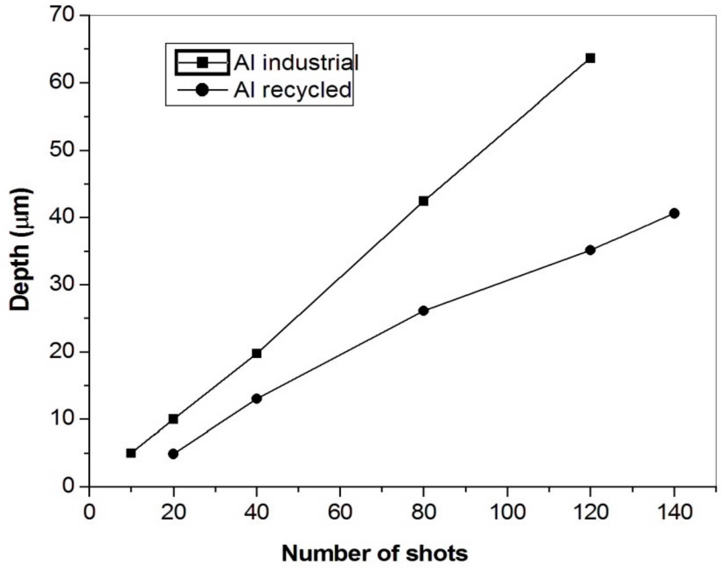

Fig. 1 The ablation depth as a function of the number of shots for industrial and recuperated aluminum.

The rate of metal ablation by laser has been studied in two aluminum alloys (industrial and recovered) this parameter can help us to choose the fluence domain appropriate to each desired technique (surface treatment, marking, cutting, …… ..)
The ablation rate industrial aluminum is more important that in recycled aluminum, because the first has a low density (for the same number of shots, depth is more important in industrial aluminum than in recycled aluminum, which leads to an ablation rate with the same variation.
In Figure 2, the ablation rate for fluences below the threshold ablation fluence (The threshold ablation is around $7J.cm^{-2}$ for recuperated aluminum and 10 $J.cm^{-2}$ for industrial aluminum [14]) increases with increasing fluence.

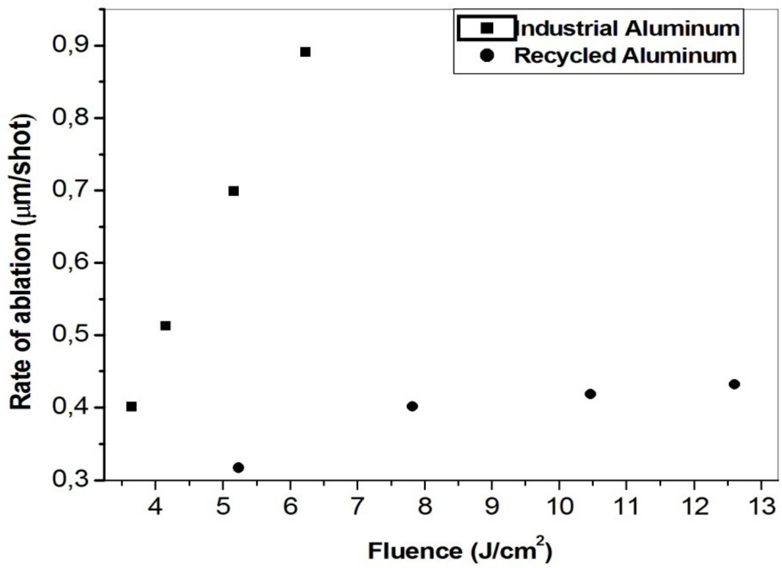

Fig. 2 The ablation rate as a function of different fluences

For most materials, especially metals, the rate of ablation progresses in three stages with increasing fluency (Fig. 2). At low fluence, close to the ablation threshold, the rate of ablation increases slowly and is associated with the photomechanical interaction [11].
Beyond a certain empirical threshold, ablation undergoes stronger growth and is governed by electronic diffusion in the material, with a trend identical to the previous one.
Finally, at very high fluence, saturation takes shape where the ablation rate tends to stabilize.
Colombier et al [16] found that a significant part of the incident energy was lost due to the ablation plume that would compress the strained material in the ablated cavity, thus limiting the ejection efficiency [16]. By comparison of the ablation rates in the two alloys studied (industrial and recycled aluminum) shown in Figures2 and 3, we can see for the same value of fluence, the ablation rate in industrial aluminum is superior than in recovered aluminum. This difference has several causes, we can cite the chemical composition of each alloy, the ablation threshold,…..,but the shape of the two curves remains the same as studied for other metals like copper [6].
The ablation rate depends on the composition of each alloy, the ablation threshold fluence, and at the applied fluencies.

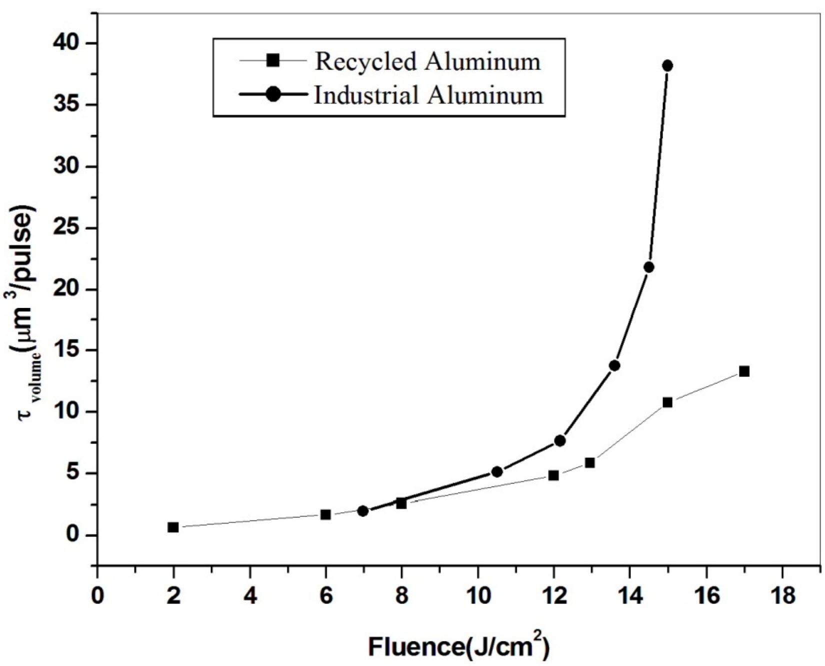

Fig.3 The ablation volume rate as a function of different fluences

Figure 3 shows that the variation in the volume ablation rate is very slow at low fluences, which explains the small amount of material ejected.
Volume rate analysis is simplified by the 3-dimensional characterization of the energy absorbed by a material, i.e. the simultaneous consideration of depths, diameters and machining shape. It is therefore relatively close to reality, and is often used to characterize laser cavities (such as drilling) [17, 18].

4. Conclusions

Based on the results of this study, we can use rate curves in order to quantify the speed of deep machining as a function of the laser parameters. Because they facilitate the choice of laser parameters for the desired treatment.

Finally, the advantage of the laser ablation approach lies in its potential to precisely control the micromachining process (engraving, drilling, cutting...). It makes it possible to identify the main macroscopic characteristics of ablation and is found to be an effective way to estimate machining speeds (to estimate the desired depth of drilling or size of a hole in a piece when it is manufactured). To achieve this, we need to be able to assess in real-time, during ablation, when the beam has reached the material.

Acknowledgements

This work was carried in CDTA center.

The author would like to acknowledge the assistance of Pr Yaser Ahmed Youcef, Chemistry Dpt., Yarmouk University Irbid (Jordan), for his help in laser radiation and Pr Tahar Kerdja, Algiers, for his help in CDTA center.

References

[1] Zhang P, Jiaheng Y, Yaowen C, Yongzhi C, Lihua L,Yongda Y, Zhengjiang H, Journal of materials research and technology 19, (2022), 40708-4720.

[2] Chong H, Mitchell A, Hayes J.P, Austin M.W, Appl. Surf. Sci, 201 (2002) 196.

[3] Chen K, Ihlemann J, Simon P, Baumann I, Sohler W, Appl. Phys. A, 65 (1997) 517.

[4] Faiza Meriche, Doctoral thesis, University Paul Verlaine - Metz, France, (2008).

[5] DeglInnocenti R, Reidt S, Guarino A, Rezzonico D, Poberaj G, Günter P. J, Appl. Phys.100 (2006) 113121.

[6] Ródenas A, Sanz García J.A, Jaque, Torchia G.A, Mendez C, Arias I, Roso L, Agulló-Rueda F, J. Appl. Phys, 100 (2006) 033521.

[7] Deshpande D.C, Malshe A.P, Stach E.A, Radmilovic V, Alexander D, Doerr D, Hirt D, J. Appl. Phys, 97 (2005)074316

[8] Bruneau S, Hermann J, Itina T, Sentis M, *J. Phys IV France*, (2003) 108.

[9] Yoan Di Maio, Doctoral thesis**,** University Jean Monnet Saint-Étienne (2013).

[10] Sirnivasan R., J. Vac. Sci. Technol. B, 1 (1983) 923.

[11] Nolte S, Momma C, Jacobs H, Tunnermann A, Chichkov B. N, Wellegehausen B, Welling H, J. Opt. Soc. of Am. B, 14 (1997) 2716.

[12] Preuss S, Demchuk A, Stuke M, Appl. Phys. A, 61 (1995) 33.

[13] Baziz L, Nouiri A, and Y. A. Youcef, J. Laser Physics,**16**, (2006)12, 1643.

[14] Baziz L, Doctoral Thesis, University Constantine, Algeria (2007).

[15] Thibault GENIEYS, Doctoral thesis, University d'Aix-Marseille France, (2019).

[16] Colombier J. P, P. Combis, Bonneau F, Le Harzic R, and Audouard E, *Physical Review* B 71, (2006), 165406.

[17] Sanner N, Utéza O, Bussiere B, Coustillier G, Leray A, Itina T, and Sentis M, *Applied Physics A*, 94(4) (2009), 889–897.

[18] Bonse J, Geuss M, Baudach S, Sturm H, and Kautek W, *Applied Physics A*,69 (1): (1999), S399 – S402.