Effects of Focused IR Laser Pulse on Aluminum by Multi Focal Length Lens

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Lasers are very important especially in research and industries. They offer directionality, high intensity, non-contact process, cleanliness and high precision. In this paper, the researcher aims to investigate the focusing effects of long pulsed IR laser on aluminum target using wide range of lenses. A Nd:YAG laser was used as an energy source. It has wavelength of 1064 nm with pulse duration 4 ns. The pulse energy delivered is 290 mJ at frequency 1 Hz and peak power of 72.5 MW. Wide ranges of biconvex lens were used to focus the laser beam on an aluminum target. A video camera was used to visualize and record the event of laser-aluminum interaction. The interaction regions on the aluminum were magnified and visualized using metallurgical microscope and then analyzed with the aid of image processing system. The image recorded during laser-aluminum interaction shows the formation of aluminum plasma plume. Experimental results show that the hole size of the aluminum is increasing as the lens focal length gets longer.

Keywords: Laser, Plasma, Focus, Aluminum, Lens.

I. INTRODUCTION

Lasers become practical tools nowadays. They are now been used in many fields such as in scientific research experiment as well as in industries [1]. The laser offers wide potential application in different areas of research relevant to material treatment, physical analysis, photo deposition, depth profiling and many other areas [2]. Laser provides high accuracy, precision, cleanliness and the most important is it provides un-contact processes with the target material [3]. When a high peak power of laser pulse is focused to the material its energy will heating, melting and vaporizing the material.

When high peak power of laser pulse is focused by a lens on the metal surface, the beam makes contact with the surface consequently heating the metal. This results in the ablation of the metal target [4]. The temperature at the heated region can achieved up to thousands of Kelvin in less than a second [5]. Laser pulse affecting the metal surfaces could lead to phase transformation and structural changes as a result of physical and chemical processes. Laser metal surface interaction depends on the laser beam parameters; such as laser pulse power density, intensity, wavelength, beam divergence, beam diameter, incident angle and processing time. In addition the metal parameters are also important such as microstructure, chemical composition, thermal conductivity, phase, surface morphology and absorption [6]. These processes also affected by ambient atmosphere where the laser metal interaction occur.

Laser plasma interactions with aluminum were extensively studied by researchers. Aluminum is widely used in fundamental research and industries due to its low density, high thermal conductivity and good resistance to the corrosion ambient at room temperature [7].

Let us consider a laser beam propagated in the form of Gaussian beams. The beam cannot merge into a sharp point, but rather has a beam waist w_o, as illustrated in Fig. 1.

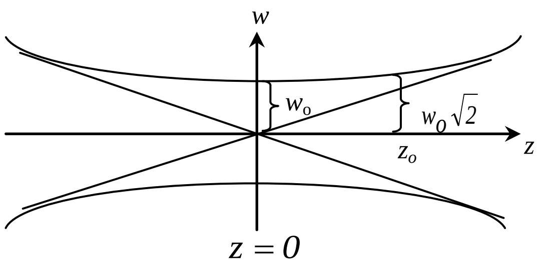

Fig. 1 Laser beam in the form of Gaussian beam after been focused by lens. At a focal point, z = 0, the beam waist is w_o and at Rayleigh region z_o the beam waist is extend to $w_o\sqrt{2}$.

The smallest point of focusing beam is known as a beam waist, w_o. It is measured from the optical axis to the smallest point of the beam edge. The intensity and the temperature in this area are very high. The beam waist at focal point ($z = 0$) could be calculated from the equation;

$$w_o = \sqrt{\frac{2z_o}{K}} = \frac{z_o \lambda}{\pi} \qquad (1)$$

where z_o is a Rayleigh range, K is wave number and λ is wavelength. From equation (1), the beam waist is dependent to Rayleigh range [8] – [9]. In other words, the Rayleigh region is a region where the beam waist is still consider small. Hence this is also known as damaging region. Target material will suffer damage once it is being placed along this region.

In practice, the beam spot can be estimated from the optical alignment [10];

$$r = \frac{\lambda}{\pi} \frac{l}{2a} \qquad (3)$$

where r is the radius of the beam spot, l is the focal length of the lens, and a is the radius of the aperture.

The aim of this research is to characterize the laser plasma interaction with aluminum target. The influences of laser peak power and lens focal length on the interaction area size created on aluminum were also investigated.

II. EXPERIMENTAL SETUP

A Q-switched Nd:YAG laser with 1.06 μm wavelength and 4 ns pulse duration was employed as a source of energy as shown in Fig. 2. In this experiment, an aluminum sample was used as a target material. It was cut into 2.0 cm × 1.0 cm in dimension. The Nd:YAG laser with energy 290 mJ operating at 1 Hz was focused by using several lenses with different focal lengths, ranging from 50.2 mm to 150.0 mm. The exposed area on the target material was then examined under metallurgical photomicroscope. A high quality CCD digital camera was used to record permanently the interaction effect. The images then analyzed and characterized using image processing software.

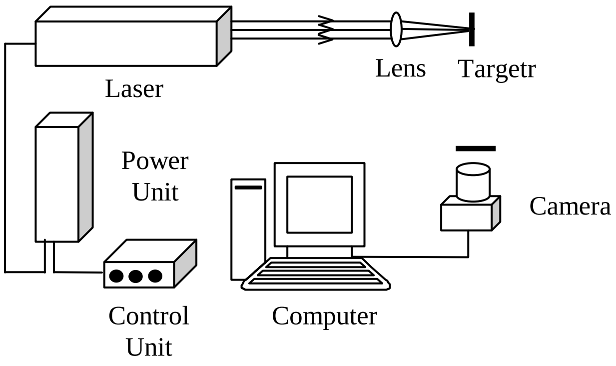

Fig. 2 Experimental setup of IR laser plasma interaction with aluminum target.

III. RESULTS

Typical results obtained from the experiments are shown in Fig. 3. The images were arranged with increasing focal length of the lenses. The laser interaction on the aluminum target creates hole because of the high peak energy of the laser pulse. They can be seen clearly from the set of images.

There are three regions in the sample images that were affected by the laser energy. The first region is the hole itself created by the laser pulse energy. This hole was created because the laser pulse energy with very short duration induced a very high peak power on the focused region up to tens of megawatts. When brought to focus, this high peak power will induce a very high intensity region achieving up to 10^{10} W/cm^2. It is also clearly shown that the size of the hole is increasing as the focal length of the lens gets longer. In addition the shape of the hole becomes more circular at longer focal length than at the shorter focal length.

The second region is the molten area. This area can be observed clearly starting from the edge of the hole and transversely away from the hole. This molten area called molten pool is the area that receives lesser laser intensity than at the center. This means that the energy as well as the peak power at this area were not enough to evaporate the materials and creates hole at that region.

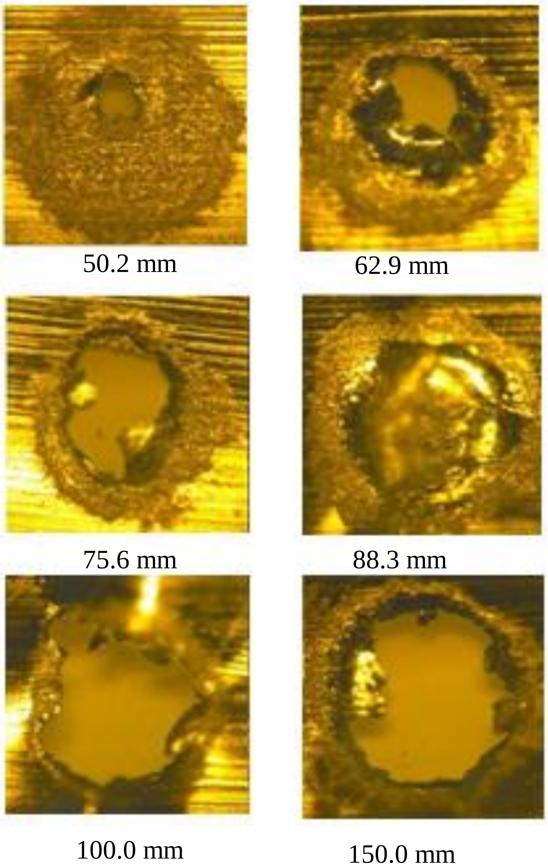

Fig. 3 Images of laser plasma interaction with aluminum target.

Thirdly is the region of debris. When pulsed laser beam is brought to the focus by lens on a target material, the material will receive such a very high quanta of energy. This energy with very short duration will be absorbed by the target material. As a consequences, the material will melted and vaporized ejecting aluminum plasma out of the surface. When the process was stopped, and no laser pulse energy bombarding the aluminum, the ejected aluminum debris will become cold and deposited around the interaction area, thus forming aluminum debris area or region.

Besides the hole images on the aluminum after the interaction, image of pulsed laser induce hot plasma during the interaction process was also grabbed and recorded. Fig. 4 shows plasma plume and plasma jet at a time bombarding the aluminum target. The image was saturated since the intensity of the focused laser radiation was very high. In order to reduce the intensity detected by video camera, wavelength and light intensity filter can be applied. From the image, a circular bright image known as pre-formed plasma can be clearly seen before in reaches the target. Then when it reaches on the aluminum surface, a white bluish spark followed by an audible sound was observed. Plasma aluminum plume was created on the target surface accompanied by plasma jet. During this process, that was in a very short period, the aluminum was heated, melted and vaporized thus creates hole on the target area.

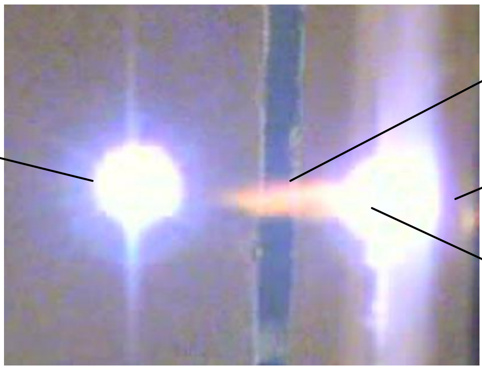

Fig. 4 Pre-formed plasma, plasma jet and aluminum plasma plume during interaction with aluminum target.

IV. ANALYSIS AND DISCUSSION

The size in term of hole diameter created on the aluminum were measured by using image processing software. As the hole were forming such a peculiar and oval-like shape at shorter focal length lens before becoming almost circular at longer focal length, the mean diameter of hole were measured and calculated.

A graph of hole diameter versus lens focal length was plotted as in Fig. 5. From the graph, it was clearly shown that the size of the hole is gradually increasing at shorter focal length but a bit slow increment at longer focal length. At shorter focal length, the experiment findings was agreeing with the theoretical, where the interaction area will get larger as the focal length gets longer. The smallest hole diameter was measured as 0.257 mm for 50.2 mm focal length lens, while the longest was measured as 1.195 mm at lens focal length 150.0 mm.

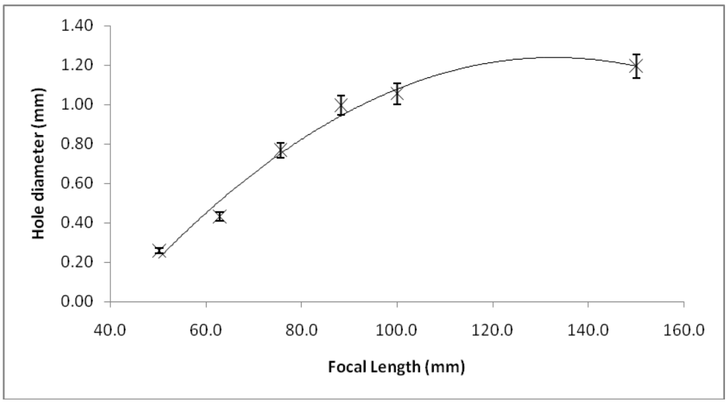

Fig. 5 Hole size on aluminum target as a function of lens focal length.

One of the factors that induce such a peculiar oval-like shape of the aluminum hole is the generation of multiple shock waves as shown in Fig. 6. The multiple shock waves produced very gross interaction. When such gross mechanisms delivered on the aluminum, the plasma become scatters before they can transfer the heat into the aluminum thus results in very peculiar shape of hole. The contaminations generated during plasma interaction also responsible in adding and cause a peculiar oval-like shape of the hole.

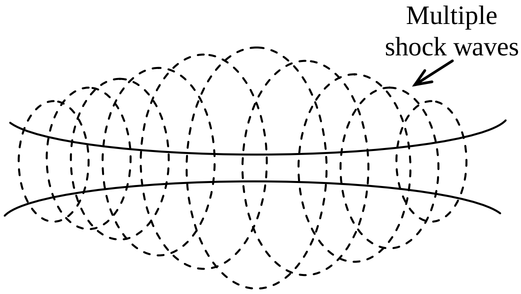

Fig. 6 Multiple shock waves induced when the pulsed laser beam is brought by a lens.

When laser plasma impinges on an aluminum target, some of the energy is reflected, absorbed and scattered. Aluminum can conduct heat hence the incident energy will be absorbed within a skin depth. At high laser power density, intense heating of the surface will occur with temperature of up to tens of thousands Kelvin and the reflectivity will fall to perhaps half of its normal value. Under this condition the heat cannot be conducted away quickly enough to prevent the surface temperature reaching the melting point and as a result a molten pool of aluminum will form.

The delivered laser pulse power density will cause the surface temperature of the target increasing thus induce molten pool. Further increase in temperature then causing the interaction region to reach boiling point and evaporation will occur. This will happen when the energy deposited is approximately equal to the latent heat of the aluminum. Such a rapid evaporation of material exerts an ablation pressure on the molten material causing droplets to be ejected. Under these conditions hole above of hundreds of μm diameter can be formed on the aluminum targets. The evaporated vapor is further heated by the laser light forming a plasma plume on the target material.

The heat transferred by the plasma will melt and weaken the surface of the target. The pressure from the shock waves causes the dent on the surface. After multiple impacts, the dent gets deeper and deeper consequently creating the hole. The schematic diagram of the plasma associated with the generated shock waves on aluminum is shown in Fig. 7.

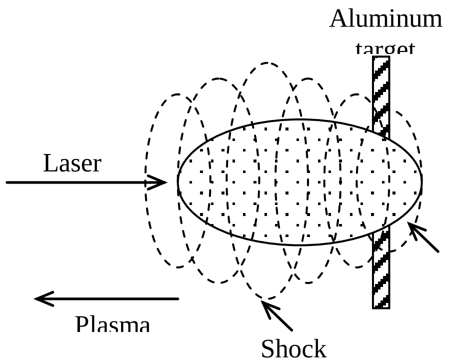

Fig. 7 Plasma generation associated with shock waves impinges on aluminum.

V. CONCLUSION

Laser plasma interaction with metal target, that is aluminum, was successfully conducted. In general there are three region formed on the aluminum after the process that is the hole, molten pool and cold ejected debris region. The holes are oval-like shape at the shorter focal length but become almost circular at longer focal length lens. The hole diameter were increasing with the focal length lens especially at shorter focal length but a bit slow increasing at longer focal length. The smallest hole diameter was measured as 0.257 mm for 50.2 mm focal length lens and the longest is 1.195 mm at lens focal length 150.0 mm. The interaction region also become cleaner and sharp especially at longer focal length.

Acknowledgement: The author would like to thank to the Ministry of Higher Education, the Government of Malaysia and the Universiti Tun Hussein Onn Malaysia for the financial and motivation support through the FRGS grant vote 0733.

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