

Laser-driven flyer application in thin film dissimilar materials welding and spalling



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ABSTRACT

This paper applied a low cost method to pack and drive laser-driven flyer in the applications of welding and spalling. The laser system has the maximum energy of 3.1 J, which is much lower than that used in the previous study. The chemical release energy from the ablative layer was estimated as 3.7 J. The flying characteristic of laser-driven flyer was studied by measuring the flyer velocity at different locations with photonic Doppler velocimetry (PDV). The application of laser-driven flyer in welding Al and Cu was investigated at different laser spot size. Weld strength was measured with the peel test. Weld interface was characterized with optical microscopy (OM) and scanning electron microscopy (SEM). The study of application of laser-driven flyer in spalling was carried out for both brittle and ductile materials. The impact pressure was calculated based on the Hugoniot data. The amount of spalling was not only related to the impact pressure but also related to the duration of impact pressure. The fractography of spalled fracture surface was studied and revealed that the fracture mode was related to the strain rate. The spall strength of Cu 110, Al 1100 and Ni 201 was measured and was consistent with the literature data.

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1. Introduction

Laser-driven flyer was extensively studied in the field of shock physics to measure equations of state (EOS) [1]. In this application, the deposition method was generally used to pack the laser-driven flyer [2,3]. The layers needed to be deposited on the substrate include ablative layer, protective layer and flyer layer. However, the deposition method is not practical in its application of welding, forming, punching etc. In this study, all the components used in laser-driven flyer are commercial products. The details of the proposed laser-driven flyer packing method can be found [4].

Welding of dissimilar metals at millimeter and/or micrometer scale is needed in many fields. The detrimental result of dissimilar metal welding with fusion welding is the formation of continuous intermetallics. Recent years, many methods were developed to join dissimilar materials, like friction stir welding, ultrasonic welding and cold welding. Laser impact welding was recently proposed and the joining of Al and Ti with laser impact welding was extensively studied by Wang et al. [5]. The advantages of laser impact welding are quick, precise and small scale. It has potential application in high requirement from those aspects.

In the study of spall strength measurement, the common method is laser irradiation. The shock wave was applied on the surface of the ma-

terial directly by pointing the laser to the material surface. The shock wave is related to the incident laser intensity, rise time, and laser pulse temporal width [6]. Summary of several literatures with the laser irradiation method is shown in Table 1. One common character of those studies is that the high energy laser was used (up to 1600 J). The strain rate was in the range of 10^6 s^{-1} – 10^7 s^{-1} . The huge cost of laser system limits the study of spall with this relatively convenient method world widely.

In this paper, the application of laser-driven flyer in welding and spalling was investigated. The welding of Al foil to Cu sheet was studied with varied laser spot size. The potential method to increase the weld area was proposed. The study of spalling was used to prove the application of laser-driven flyer in spall strength measurement with such low laser energy. The diagnostic system used to measure the free surface velocity of the target material after shock load is photonic Doppler velocimetry (PDV).

2. Experimental setup

In this study, a commercially available Nd:YAG laser was used. The system is a Continuum PowerliteTM Precision II Scientific System. The maximum output energy was 3.1 J with a pulse width of 8.0 ns and wavelength of 1064 nm. The detailed description about the laser

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Table 1
Summary of literature about spall study with laser irradiation method.

Investigator	Laser (J)	Material	Thickness (μm)	Strain rate ($\times 10^6 \text{ s}^{-1}$)	Spall strength (GPa)
Moshe et al. [7]	10–80	Aluminum	50	9.0–40	0.7–4.3
		Copper	38	10–27	3.0–9.0
Pedrazas et al. [8]	1600	Al1100	500	3.5	3.0
Dalton et al. [9]	1200	Aluminum	200–500	2.1–6.6	2.4–4.2
Fortov et al. [10]	100	Aluminum	100–600	10	2.0–3.0
		Copper	100–600	10	2.0–3.0
Lescoute et al. [11]	180	Aluminum	200–250	1.9	4.5
		Iron	150–250	1.7–2.4	3.8–4.9
		Gold	300	1.9–2.4	4.1–4.5

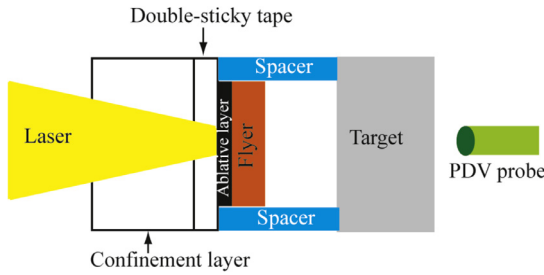


Fig. 1. Schematic experimental setup for spall strength measurement. PDV measures the velocity of rear (free) surface of the target. There is no connection between the target and the spacer. After the flyer collides on the target, the target is free to move forward.

system can be found in [4]. The schematic experimental setup is shown in Fig. 1. The confinement layer was 3 mm Heat resistant borosilicate glass. The ablative layer was commercially available spray paint (RUST-OLEUMTM, Enamel), which was painted on the flyer surface directly. The connection between the confinement layer and the painted flyer was the clear double-sticky tape. During the experiment, the laser ablates the ablative layer. The hot, rapid expanding plasma from the vaporization of ablative layer drives the flyer to move toward the target with a velocity up to a thousand meters per second.

For the purpose of flyer velocity measurement, the target was transparent polycarbonate for PDV probe to detect the movement of the flyer. The polycarbonate also protected the PDV probe to be damaged by the flying flyer. In the study of flyer's flying characteristic, the flyer was Al1100 with dimension of 12 mm \times 12 mm. Laser spot size was 4 mm. In order to study the flyer dimension effect on the velocity, 4 mm \times 4 mm and 7 mm \times 7 mm flyer were also used for flyer velocity measurement. In the study of impact welding, the flyer was 25 μm thick Al1100 and the target was Cu110 sheet. The laser spot size of 2 mm, 4 mm and 6 mm was used. The peel test method was introduced in details in [5]. In the study of spalling, the target was not fixed and was free to move after the impact with flyer. The PDV [12] was used to record the velocity of the free (rear) surface of the target. The flyers used in this study included Al1100 (75 μm thick) and Ni201 (25 μm thick). The flyer effect on the spall phenomenon of Cu110 (500 μm thick) and Al 2024 (560 μm thick) was investigated. The spall strength of Cu110 (150 μm thick), Al1100 (250 μm thick) and Ni201 (100 μm thick) was calculated with the free surface velocity measured with PDV. The corresponding fractography of the spalled surface was studied with SEM.

3. Results and discussion

In the experiment, the ablative layer was spray paint. Assume the paint is 50% inert filler, 50% hydrocarbon. The combustion of hydrocarbon releases chemical energy which benefits the process. It is hard to control the uniformity of the ablative layer. Roughly it had the thickness of 50 μm . However, not all the paint vaporized during the interaction with laser. The loss of the ablative layer was measured with 4 mm laser spot size. 25 μm thick nickel was painted with the ablative layer. Then

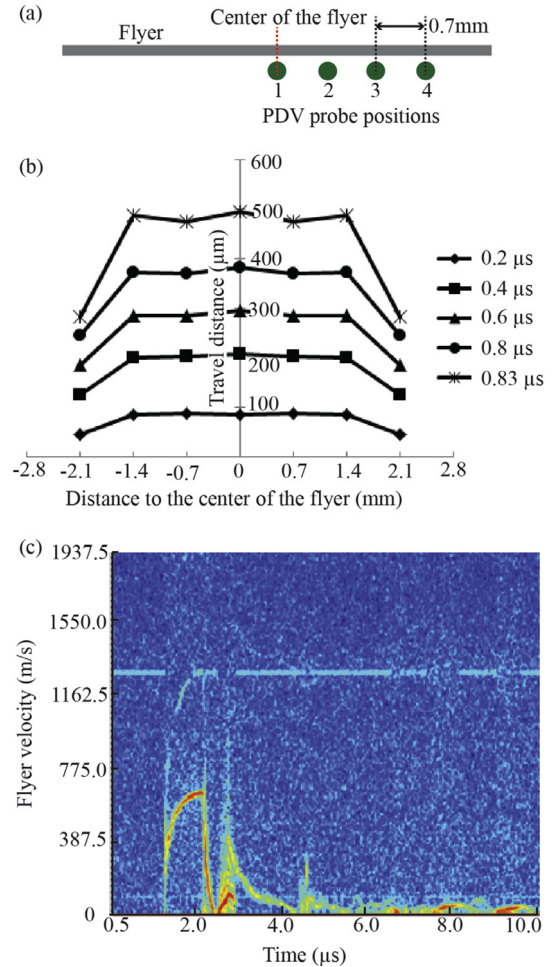


Fig. 2. PDV locations for flyer velocity measurement. (b) Flyer profile at different time during flying. (c) A typical flyer velocity profile at the center of one flyer.

it was cut into circular shape with 6 mm diameter. Three of them were measured before and after laser shot. The average value is $7.583 \times 10^{-3} \text{ g}$ and $7.287 \times 10^{-3} \text{ g}$. Therefore, the loss of the paint is $2.97 \times 10^{-4} \text{ g}$. The enthalpy of combustion of hydrocarbon per gram is 25 kJ [13]. Therefore, the chemical energy from the hydrocarbon combustion is 3.7 J. By purposely designing the paint, the released energy from chemical reaction can be higher.

3.1. Flying characteristic of laser-driven flyer

The locations of PDV probe relative to the 75 μm Al1100 flyer are shown in Fig. 2(a). One location is at the center. The distance of other three locations to the center of the flyer is 0.7 mm, 1.4 mm and 2.1 mm. Seven experiments were repeated at each location. A typical flyer veloc-

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