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Effect of beam size in laser welding of ultra-thin stainless steel foils

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ABSTRACT

Experiments were conducted to study the weldability of a 50 μm-thick AM350 stainless steel foil onto a 1 mm-thick SUS304 stainless steel sheet using a 2 kW multi-mode fiber laser. To enhance the contact between the foil and the substrate, a vacuum-assisted jig was designed and used, and four different beam diameters (200, 375, 625, and 1125 μm) were considered to study the effect of beam size on weldability. For each beam diameter, a process parameter space consisting of 25 experiments was constructed systematically such that the constructed spaces for different beam diameters were qualitatively similar in terms of penetration depth and welding mode. High-speed video imaging was utilized to study the mechanisms of melt pool disruption and droplet formation, and dust and cavity distributions on the specimens were also investigated. It was found that the effect of beam diameter is significant in the ultra-thin foil welding, and a smaller diameter is highly preferred. For larger beams, the surface tension effect becomes too large to sustain a stable weld pool. Tensile strength and hardness were found to be inversely proportional to the penetration depth.

1. Introduction

Thin metal foils are finding more and more applications in various industries, such as automotive catalyst systems, diaphragm sensors, and medical components (Petrich et al., 2014), but the welding of metal foils still remains a challenging task due to a number of technical difficulties. For example, the heat input needs to be precisely controlled because the excess heat input could lead to defects in the weldment (Du et al., 2000). Furthermore, the specimens must be held tightly by using a high-precision welding jig in order to avoid any alignment and gap problems.

A great deal of effort has been made by researchers in applying the laser welding technique to the joining of thin metal foils which are thinner than 100 μm. P'ng and Molian (2008) studied the Q-switched pulsed Nd:YAG laser welding of 60 μm thick SUS304 foils and compared the results with those of resistance welding. Their results showed that laser welding required nearly three times less heat input and produced welds having 50% narrower seams, 15% less porosity, 25% more strength and improved surface aesthetics. Abe et al. (2003) studied laser welding of 50 and 100 μm thick SUS304H foils. In their study, they found that the foil thickness should be smaller than 1/3 of the bead width for successful welding. Park et al. (2003) investigated the Yb fiber laser welding of 10–60 μm thick SUS304 foils using a focused beam diameter of 10 μm. In their work, they studied the formation of keyholes, the influence of assist gas, and carried out a thermal analysis for the micro-welding process. Patschger et al. (2012) studied the laser remote welding of 15–100 μm thick SUS304 foils using a single-mode fiber laser equipped with a scanner head. They successfully demonstrated that the presented remote welding method was suitable for the welding of ultra-thin foils. Ventrella and Berretta (2010) investigated the pulsed Nd:YAG laser welding of 100 μm thick SUS316L foils and found that pulse energy control was critical in obtaining good quality welds and the process was very sensitive to the gap. In a similar work, they also used the same pulsed laser welding method for the joining of 100 μm thick Monel 400 foils, which is a nickel-copper alloy (Ventrella and Berretta, 2011).

This paper systematically and extensively investigates the effect of beam size on weldability and tensile strength in the multi-mode fiber laser welding of ultra-thin stainless steel foils. A 50 μm thick AM350 stainless steel foil was welded onto a 1 mm thick SUS304 sheet in a lap welding configuration using four different beam diameters (200, 375, 625, and 1125 μm). In order to enhance the contact between the specimens, a vacuum-assisted jig was used to

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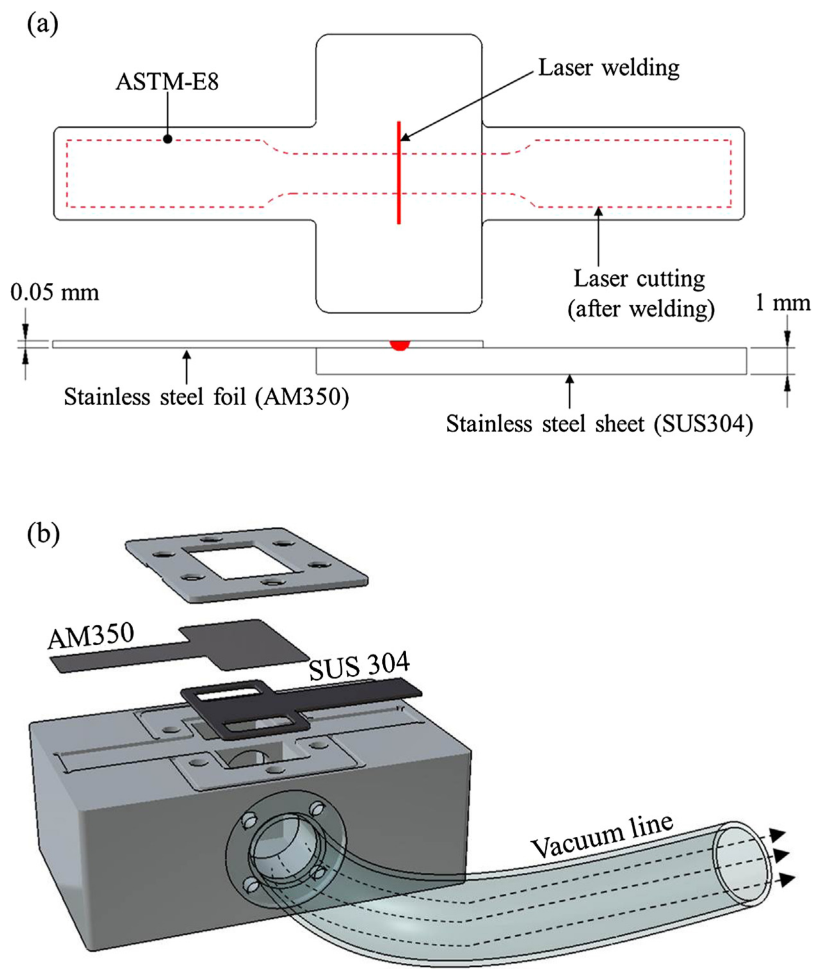

Fig. 1. (a) Dimensions and shapes of the welding specimens. An AM350 foil is placed on top of 1mm-thick SUS304 sheet and the laser beam is scanned along the centerline. The red dashed line represents the ASTM-E8 tensile test specimen that is laser-cut after the welding experiment. (b) A schematic view of the welding jig, where a vacuum force induced by a rotary pump is introduced to enhanced the contact between the specimens. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

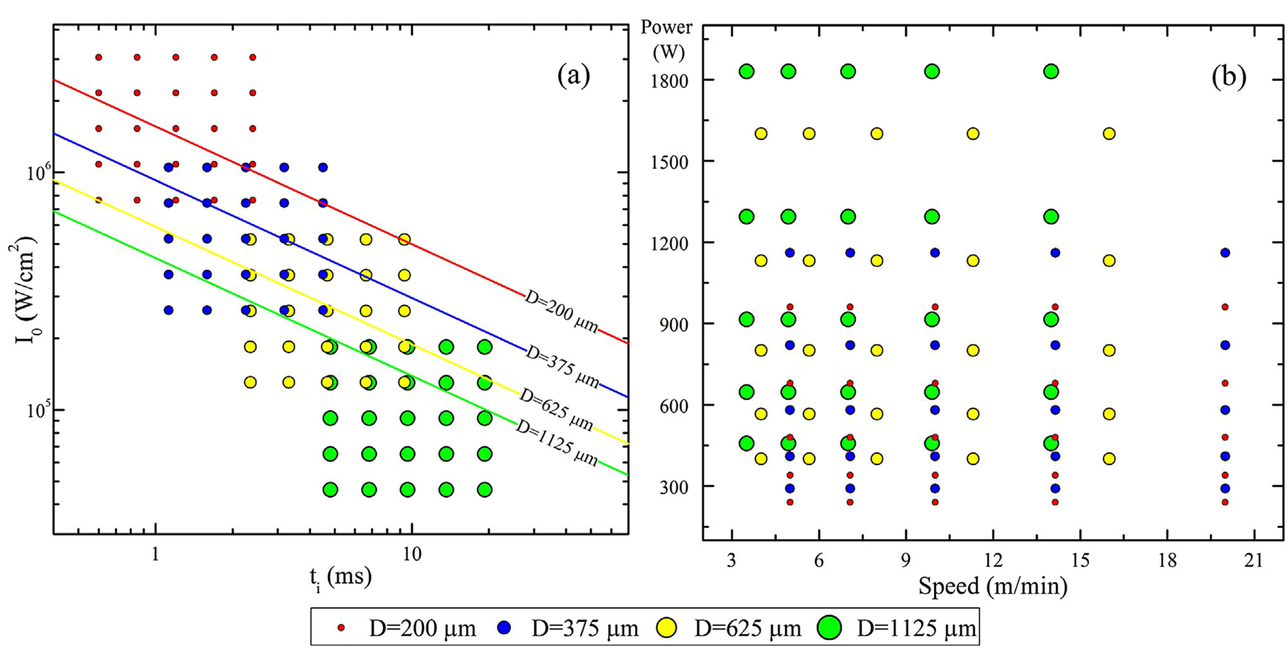

Fig. 2. Design of experiment. All the experimental conditions are shown (a) on an intensity-interaction time diagram and (b) on a laser power-beam scanning speed diagram. (For interpretation of the references to colour in the text, the reader is referred to the web version of this article.)