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Research Note

Making interlock by laser shock forming

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A B S T R A C T

A novel processing technology for interlocking and joining three sheets of two copper foils and a perforated stainless steel sheet by laser shock forming is presented in this paper. In this forming process, two layers of ductile copper foils are positioned above a perforated stainless steel sheet, a shock pressure induced by pulsed laser is applied on the upper foil, both foils are indented downwards through the hole of the perforated sheet, and impact on the rigid bottom support, then spread radially to produce a double interlock, thus to join the three sheets together. Finite element analysis as well as practical experiments were conducted to verify the feasibility of making interlocks by laser shock forming. The numerical simulation reveals the deformation mechanism of interlocks based on the analysis of plastic flow and shape evolution during the process. These results point to the practicality of clinching and joining three sheets by laser induced plastic deformation, namely laser shock joining or laser shock clinching.

1. Introduction

Joining by forming, as a mechanical joining process, is becoming attractive with an increasing demand for multi-material joints production and for saving energy and resources [1,2]. One typical mechanical joining process is mechanical clinching, in which the sheets are joined without the use of subsidiary materials or any rivets, but rather an interlock produced by squeezing with a punch and a die. Sufficient sheet thickness is demanded as the interlock is locally deformed due to the different plastic deformation through thickness of the sheets [3].

Laser shock forming, serving as a high speed forming process of cups [4] and hemispheres [5], has been extended to a joining technique for metal sheets. Ji et al. [6] first introduced a novel concept of micro scale laser shock clinching. A metal foil is deformed into an undercut by pulsed laser beam, and interlocked with a perforated sheet, which results in mechanical joining between different materials. Veenaas and Vollersten [7] conducted experiments to investigate the effects of hole size and the sheet thickness on the undercut, their results show the possibility of joining aluminum to stainless steel by means of TEA-CO_2 laser induced shock waves. Wang et al. [8] achieved the connection of similar and dissimilar metal foils in micro scale by integrating laser cutting and clinching.

Almost all of the previous work in joining by laser shock forming is aimed at joining one intact sheet and another perforated sheet, however, joining two intact sheets or joining three sheets together, has not been investigated so far. The present paper proposes a new method to clinch two copper foils and a perforated stainless steel sheet by laser shock forming. In practice, the perforated sheet can be also used as a rigid tool in joining two foils. This process could meet the requirements for joining similar or dissimilar materials, and would have great potential in automobile and micro-manufacturing industries.

The focus of this current work is to demonstrate the practical feasibility of forming two sheets into local undercuts and then joining to a sheet with a predrilled hole. Large interlock between the two copper foils, as well as the interlock between the copper foil and the perforated sheet, were obtained in the experiments and observed under microscopes. Finite element method (FEM) simulations were conducted to describe the deformation mechanism of this process.

2. Methodology

2.1. Principle of making interlock

When joining three sheets by laser shock forming, a double interlock is requisite to be formed. The principle of the deformation process is sketched in Fig. 1. Serving as the confinement layer, quartz glass is pre-coated with a thin layer of black wax as an ablative layer on its bottom side. When a high intensity laser pulse irradiates onto the ablative layer through the transparent confinement layer, the ablative coating instantaneously vaporizes as a

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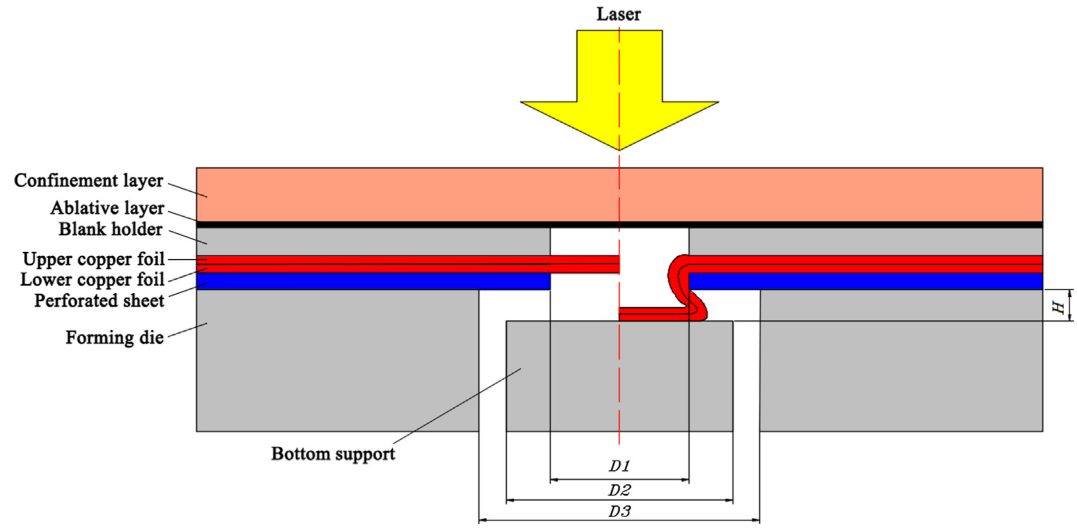

Fig. 1. Schematic diagram of making interlock by laser shock forming.

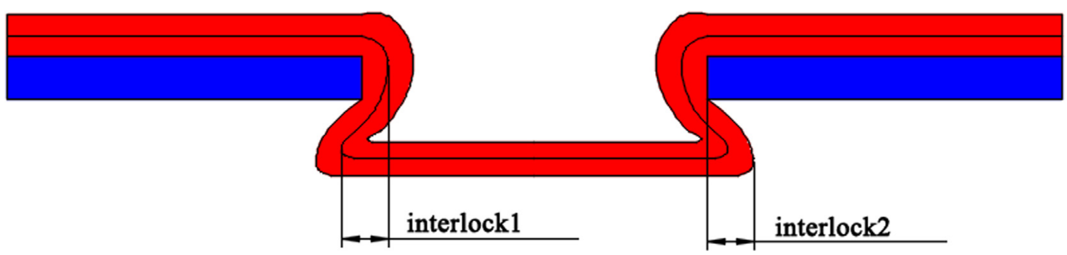

Fig. 2. Interlocking structure of the clinched joint.

high-pressure and high-temperature plasma after absorbing the laser energy [9]. Plasma expands to produce a compressive shock wave, which can only propagate towards the copper foil due to the constraints of confinement layer and blank holder. The peak pressure of the shock wave is far larger than the dynamic yield limit of the copper foils, so metal foils are forced to cause plastic deformation and strongly impact the bottom support. With increasing number of the laser pulses, a double interlock construction is eventually formed to connect the three sheets together.

Fig. 2 shows the detailed interlocking structure of the clinched joint. Two copper foils are clinched each other by interlock1, while the lower copper foil and the perforated sheet are joined together by interlock2.

2.2. Experiment procedure

As illustrated in Fig. 1, the experiment system in this study mainly consists of laser, confinement layer, ablative layer, sample materials, forming die, and bottom support.

A short-pulse Nd-YAG laser beam with Gaussian distribution (pulse width: 8 ns, wavelength: 1064 μm) was used. Pure copper foils of 30 μm in thickness and stainless steel sheet of 200 μm in thickness were employed. For increasing the ductility and formability, copper foils were annealed at 400 °C. In the annealing process of copper foils, argon gas was used as the protective gas. The heating was started after ventilating the protective gas for 15 min. The temperature was raised to 400 °C in 40 min, and then the temperature was for 60 min. Finally, the furnace was cooled down to room temperature. The stainless steel sheet was predrilled with a hole of 2.5 mm in diameter. One combination of sheets, namely "copper/copper/stainless steel", was used for joining. Both copper foils and the stainless steel were cut into a size of 15 mm × 15 mm before the operation. The die system consists of blank holder, forming die and bottom support (blank holder diameter, *D1*: 2.5 mm; bottom support diameter, *D2*: 3.5 mm; forming die diameter, *D3*: 4.5 mm; forming height, *H*: 0.2 mm).

To form an interlock, the metal foils within the predrilled hole must be completely impacted by laser beam, so the laser spot diameter is slightly larger than the diameter of the predrilled hole. The spot diameter of 4 mm remains constant during all the experiments.

The two copper foils are overlapped and clamped by the blank holder and the perforated stainless sheet. The inner diameter of the blank holder and hole diameter of the sheet have the same dimension of *D1*. The laser beam directly irradiates onto the black wax layer (about 20 μm in thickness) through the narrow hole of the blank holder, and shocks the foil again and again with multiple laser pulses.

3. Mechanism

For studying the deformation mechanism of this novel process, numerical simulations were carried out by the FEM software LS-DYNA. Two copper foils were considered as deformable parts while blank holder, bottom support and perforated sheet were modeled as rigid parts.

3.1. Loading

In the confined ablation mode, shock wave pressure lasts two to three times longer than the pulse duration [9]. Shock wave pressure was calculated based on Fabbro's model in this paper, which