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Laser shock micro clinching of Al/Cu

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ABSTRACT

The influences of ablative layer, soft punch, die depth, and laser energy on novel micro clinching of Al/Cu were investigated. Ablative layer thickness notably influenced metal flow including neck and interlock; the relationship between reasonable ablative layer thickness and certain laser energy range was summarized. Soft punch with 100 μm was more suitable than with other thickness for the process. In the joinable laser energy range, with increase of laser energy, interlock thickness gradually increased, whereas the neck and bottom thicknesses gradually decreased. The process window of Al/Cu combination was acquired, and a certain thickness difference which was at least 40 μm inevitably existed between the upper and lower metal foils. For every joinable combination, matching function of optimum die depth are derived based on Al and Cu foil thickness when the thickness of each metal foil was less than 200 μm. The single lap shearing test showed that the tensile strength and failure model of the joint both depended on neck and interlock thicknesses; only the joint that simultaneously formed a large interlock and large neck can attain a high joining strength.

1. Introduction

The coupled use of dissimilar lightweight materials challenges the joining technology of metal plates because of the different mechanical and physical behaviors of the materials. Traditional welding processes, which are based on thermal effects, are unsuitable for joining dissimilar material plates with widely different melting temperature. Thus, mechanical clinching has been developed to solve these problems. This process is increasingly replacing the conventional welding techniques, in which the materials are unsuitable for heating process. During the clinching, metal plates are joined by local cold forming between a punch and a die without additional joining elements. Compared with conventional joining technologies, such as adhesive bonding and mechanical fastening, mechanical clinching process holds numerous benefits, such as simple process, rapidity, low noise, process cleanliness, absence of surface pre-treatment and post-treatment, and high dependability. Owing to its notable advantages, mechanical clinching has been increasingly employed in metal plate joining in the automobile, construction, and electrical appliance industries.

Abundant researches on mechanical clinching involving numerical simulation and experiments are available. Ning et al. (2003) investigated the mechanism, material flow conditions, the principle of formulating of the process parameters, and joining strength of press joining technology, which provided the basic knowledge of mechanical clinching. Most studies examined mechanical clinching that utilized a fixed solid die and focused on the die geometry. Lee et al. (2010) studied the effects of process parameters which belonged to die geometry on the joint characteristics of combination of aluminum alloy and high-strength steel, and found that joining strength is determined by the neck and interlock thickness. Abe et al. (2012) achieved mechanical clinching of high-strength steel and aluminum alloy with optimized dies to control material flow and avoid failure of the joints. Abe et al. (2014) also successfully joined ultra-high strength steel sheet with modified diameter and depth of the die by mechanical clinching without sheet fracture. In addition, to improve the joining quality of combinations of different metal sheets, the researchers used many optimization methods to modify the die geometry such as Taguchi method, response surface methodology and Kriging metamodel. These methods are all effective for joining metal sheets with good ductility. However, metal sheets with reduced ductility have a limited benefit from these methods, which require special treatment. Conventionally, reduced-ductility metal sheets can be joined by a rectangular tool, in an approach called shear clinching technology, but the produced sharp edges will negatively affect the fatigue life of the joint. Lambiase et al. (2015) used preheating to achieve mechanical clinching for reduced-ductility aluminum alloys, which further extended the join ability. Besides, Lee et al. (2014) proposed a hole-clinching process, in which the plastic material was set on the upper level and the poorly plastic material was pre-holed and set on the lower level. In this process, the punch forces the upper material to flow into the hole and spread to form the interlock between the two materials, which provides a new joining technology to join high-strength materials with low plasticity. To search for a more

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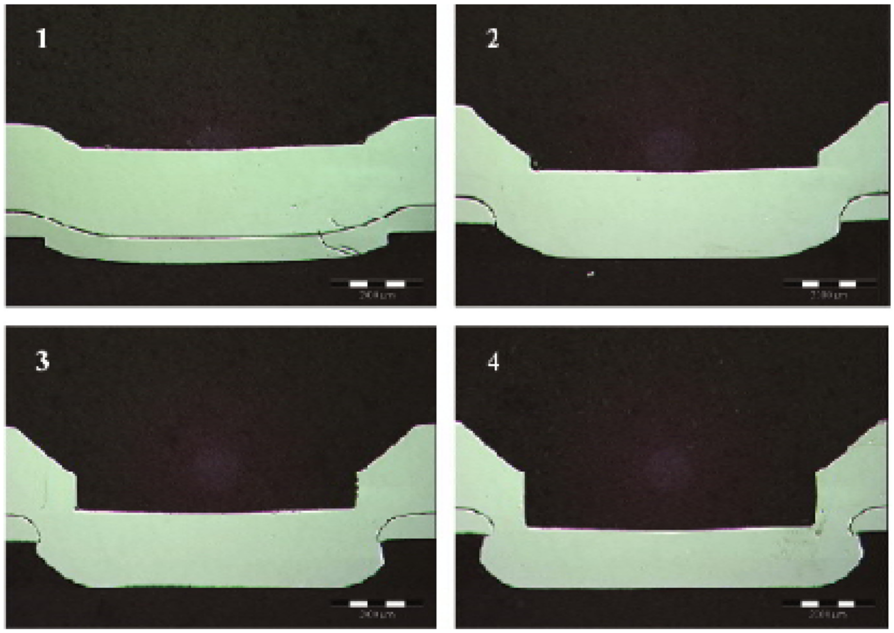

Fig. 1. Single-stage process integrating punching and clinching (Busse et al., 2010).

economical method for joining different materials, Busse et al. (2010) reported a single-stage process beyond the limit of current mechanical clinching technologies. This new process integrates the punching and clinching processes (Fig. 1), which increased the range of materials for mechanical clinching.

In recent years, especially in precision mechanics and the electronic industry, the miniaturization trend in manufacturing processes has substantially influenced the micro mechanical clinching process, which also requires coupled use of various lightweight materials. However, the mechanical clinching process is typically applied on metal plates with thickness ranging from 0.2 mm to 4 mm and seldom involves metal foils with thickness below 0.2 mm. Therefore, the mechanical clinching process is expected to offer broad application if the process shifts to the micro joining range. Moreover, the applicability of joining technology based on plastic deformation in the micro joining field is important to investigate. However, traditional mechanical clinching technologies cannot be directly transplanted into the micro clinching field because of size effect. The difficulty of fabricating suitable micro tools and the high cost also remain to be addressed. The clearance between micro punch and micro die is too small to ensure alignment accuracy, thereby reducing the tool service life and declining the joint quality. Therefore, a non-contact process without the traditional micro punch is suitable for micro mechanical clinching, facilitating the alignment and enhancing alignment accuracy.

Laser shock forming is a non-contact process that facilitates significant progress in the micro plastic deformation field. Wang et al. (2014, 2015) studied the deformation of metal foils with the aid of a soft punch through the action of laser-induced shockwaves and successfully fabricated micro parts of thin metal foils by laser shock waves with a forming/blanking compound die, which proved that the process was favorable for fabricating micro components. However, the process only slightly evolves in the field of joining by forming. Wielage and Vollertsen (2011) successfully produced an undercut of a single aluminum foil with 20 or 50 laser pulses by laser shock forming and analyzed the mechanism of undercut formation, which indirectly proved that laser shock forming could produce the interlock between metal foils. Then, Veenaas and Vollertsen (2014, 2015) applied a new high speed joining technology by laser shock forming to the micro joining field. The schematic of the process is shown in Fig. 2; a hole of 4 mm diameter is pre-drilled into the lower foil, the upper foil is stacked with the lower foil, and the two joining partners are placed on the spacer clamped by the blankholder. In the process, several laser shocks lead to plastic deformation of the upper foil, and the deformation part flows into the pre-drilled hole of the lower foil. Then, the deformation part of the upper foil spreads around upon reaching the bottom. Finally, a suitable undercut is formed between the lower and upper foil; this undercut is the key to the joining of the foils. The research verifies the feasibility of micro clinching based on laser shock forming, but it needs a pre-drilled hole and 50 laser pulses which reduces process efficiency. The cross section of the aluminum/stainless steel joint produced in the research is shown in Fig. 3, and the maximum tensile force of the joint measured by single lap shearing test is 26.7 N.

Ji et al. (2008) also published a patent on micro foil clinching, in which a new non-contact method was proposed to achieve the micro joining of ultra-thin foils by laser shock.

In the above mentioned studies, the laser shock is used to replace micro punch to join ultra-thin foils, replacing traditional mechanical clinching in the micro joining field, and providing a new method for micro clinching metal foils on the basis of plastic deformation. However, the current micro clinching process by laser shock forming requires a pre-drilled hole and many laser pulses, which vastly reduces process efficiency.

On the basis of laser shock forming, Wang et al. (2016) proposed a novel technique called micro clinching with cutting and performed a feasibility study for this method, which can achieve complete punching and collective clinching. The schematic of the process is shown in Fig. 4. The paper researched number of laser pulses, general matching relationship between total thickness of materials and die depth, and feasibility of combinations of different materials. However, the progress of this technique remains in the feasibility study stage and is far from determining the effects of various process parameters. Hence, the application of this technique is limited, and a systematic research on this technique is necessary. The paper continuously conducted studies on the micro clinching of Al/Cu foil by using a micro mold. The paper firstly identified the influences of ablative layer, soft punch, and laser energy which are the foundation to acquire process window. Then for every combination in the process window, the optimum die depth was summarized and analyzed. Tensile strength and failure model of the joint were supplementarily examined by single lap shearing test, and the relationship of tensile strength and the failure models with the